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Philosophical Capital and Sustainable Livelihoods: A Comprehensive Analysis of Small-Scale Polyculture Fisheries in Medan, Indonesia

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ABSTRACT

Beyond the conventional five-capital sustainable livelihood framework, this research reveals the significance of philosophical capital—systems of values, local wisdom, and cultural practices—as a crucial dimension in the sustainability of small-scale polyculture fish farmers in Medan City, Indonesia. Through a survey of 89 fish farmers in Medan Labuhan and Medan Belawan Districts, this study develops and validates philosophical capital measurement instruments and analyzes their contribution to livelihood system sustainability through linear and non-linear approaches. Results show that the farmers' livelihood system falls into the "quite sustainable" category (SLCI = 0.571). Social capital emerges as the dominant component (index 0.6067), while philosophical capital (index 0.5290) contributes significantly by integrating traditional values into cultivation practices. Non-linear threshold effects analysis identified significant thresholds for natural capital (0.48), philosophical capital (0.51), and social capital (0.58), revealing how these capitals contribute to sustainability through different critical points. Comparative validation confirms that philosophical capital possesses strong psychometric properties ($\alpha = 0.87$, AVE = 0.64) with the highest correlation to social capital ($r = 0.58$, $p < 0.01$). This research contributes to developing a more holistic sustainable livelihood analysis framework by identifying philosophical capital as a "meta-capital" that influences how other capitals are accessed and maintained. The implications include the importance of an integrative approach to policy development that accommodates local cultural values and dimensions as the foundation for resilience in small-scale polyculture fish farming livelihood systems.

1. INTRODUCTION

The World Food and Agriculture Organization (FAO) states that the global population experiencing food insecurity increased from 7.9% in 2019 to 9.2% in 2022 [1]. This alarming trend is triggering an increase in global protein demand by up to 70% [2], which aligns with the projected doubling of fish demand between 2020 and 2050 [3]. In this context, sustainable aquaculture emerges as a potential solution to meet the nutritional needs of the world's growing population [4]. In 2020, aquaculture accounted for 49.2% of global aquatic animal production [5], where small-scale aquaculture plays an important role in supporting food security, nutrition, and economic improvement for many households in developing countries [6-8].

In Indonesia, data from the Ministry of Marine Affairs and Fisheries (KKP) in 2023 shows a significant increase in aquaculture production over the past five years, especially in freshwater fish and shrimp commodities [9]. One of the methods that fish farmers widely adopt in various regions in Indonesia is the polyculture system [10]. Fish polyculture has evolved into an innovative approach in modern aquaculture practices with the main goal of improving the efficiency of feed resource utilization in ponds through consideration of trophic hierarchy and feeding behavior of each cultivated species [11]. This system optimizes biomass growth by carefully selecting the most suitable species combinations [12].

Polyculture fish farming has become a method widely adopted by fish farmers in Indonesia; one example is in Medan, one of the centers of brackish water cultivation in North Sumatra Province [9]. Fish farming production in this city is recorded to reach 177.20 tons in 2023, with coastal districts such as Medan Labuhan, Medan Belawan, and Medan Marelan being the main centers [13]. Although species diversification helps farmers stabilize production and income during market fluctuations [14], the optimization of this system is still constrained by the complexity of interactions between species and environmental conditions [15].

To overcome this complexity, a sustainable livelihood asset (SLA) approach can be used, where SLA has become the main framework for understanding and improving the welfare of small-scale fish farmers, where social capital is a key component in building the resilience of coastal communities

[16]. Diartho et al. [17] stated that social networks within the SLA framework proved to be a key factor in allowing small-scale fish farmers to access the information, technology, and resources necessary for the sustainability of their livelihoods.

However, some recent studies have revealed that this approach has limitations in capturing intrinsic individual aspects, such as perspective, personal values, and cognitive capacity, in the face of uncertainty [18, 19]. In contrast to social capital, which focuses on connectivity and collective action, philosophical capital emphasizes the internal dimensions of individuals, such as self-efficacy, resilience, and reflective ability in decision-making [20]. Simbarashe and Forbes [21] stated that integrating philosophical capital into the SLA framework can strengthen the adaptive capacity of smallholders through increased intrinsic motivation and future orientation beyond the benefits derived from conventional social capital.

Through this integrative approach, this research is expected to significantly contribute to developing sustainable fisheries management strategies that accommodate both local wisdom and the demands of modernity. The results of this study will not only enrich the academic literature on philosophical capital and sustainable livelihoods but also provide practical implications for the development of policies that support the sustainability of the small-scale fisheries sector.

2. LITERATURE REVIEW

2.1 Polyculture fisheries on sustainability of livelihoods

Polyculture systems in aquaculture provide several significant ecological benefits. By utilizing complementary feeding habits of various species, these systems can improve feed use efficiency, reducing waste and increasing overall productivity [22, 23]. Recent research shows that applying polyculture systems can increase production yields by up to 30% compared to monoculture systems, especially when selected species have complementary feed needs [24]. In addition, species diversity in this system also contributes to increased resistance to disease, as variations in immune responses and ecological interactions between species can reduce disease prevalence and increase fish resilience to environmental stresses [22, 25]. Thus, polyculture supports fish health and is important in ecological sustainability. This practice contributes to the bio-economy by integrating different fish species, thereby minimizing environmental negative impacts and promoting resource recycling [26, 27].

From a social and economic perspective, polyculture systems can improve the well-being of local communities by increasing fish production and providing diverse sources of income [24, 28]. Vecchio et al. [29] found that social networks among fish farmers allow the exchange of knowledge and innovative practices, which are essential for improving the productivity and sustainability of aquaculture. The research by Manlosa et al. [30] also stated that these social networks allow fish farmers to share experiences and strategies that have worked in their contexts, thus fostering a culture of continuous learning and adaptation. Social interaction also supports the development of strong socio-ecological systems that can withstand external shocks, such as climate change and economic fluctuations, by promoting collaborative resource management and shared learning [31, 32].

Economic and food security can be achieved using a polyculture fish farming system by providing a stable and varied supply of aquatic food products [24]. Glencross et al. [33] showed that this diversification can increase local food security by up to 25%, providing better access to animal protein sources. However, the effectiveness of polyculture systems depends on selecting the right combination of species that can coexist without significant competition. It thus requires a deep understanding of ecological roles and interactions between species [33, 34]. In addition, the management of polyculture systems can be challenging, requiring careful monitoring and adjustment to maintain balance and optimize productivity [27, 35].

2.2 Conceptualization of philosophical capital in sustainable livelihood

Quandt [36], in his research, stated that the sustainable livelihood approach to developing aquaculture businesses is a fundamental aspect that needs to be understood comprehensively. He emphasizes the importance of identifying and analyzing individual assets or capital in achieving sustainable livelihood outcomes. Chambers and Conway [37], Scoones [38], and Ellis [39] developed this concept by underlining that individuals, especially the less fortunate, need innovative combinations of different types of capital to meet their living needs.

Despite the comprehensive nature of these foundational frameworks, critical analysis reveals they primarily focus on five traditional forms of capital while overlooking the philosophical dimensions that influence how these capitals are perceived, valued, and utilized. Our conceptualization of philosophical capital addresses this gap by identifying the cognitive frameworks, value systems, and cultural practices that shape decision-making processes in resource management (Table 1). In contrast to approaches that treat cultural elements as components of social capital, we propose philosophical capital as a distinct meta-capacity that influences how all other forms of capital are accessed, combined, and maintained.

In polyculture fish farming, human capital plays a vital role as the foundation for business development. Cattermoul et al. [40] stated that skills, knowledge, and employability are essential elements for the success of cultivators. Heckman and Mosso [41], in their study, also strengthen this opinion by stating that the quality of human capital varies based on the level of technical skills and adaptability to environmental changes. da Silva Maciel et al. [42] and Manlosa et al. [30] examined how social capital built through the network of cultivator communities contributes significantly to increasing the resilience of production systems by exchanging knowledge and resources.

Natural capital, which includes the availability of water, soil, and biodiversity, is critical to the sustainability of aquaculture businesses [43]. Jamwal et al. [44] revealed that overexploitation of natural capital can threaten business sustainability, emphasizing the importance of environmentally friendly cultivation practices. Physical capital, including infrastructure and production facilities, optimizes productivity. Yigit et al. [45] proved that the right infrastructure design can improve the efficiency of the overall aquaculture system.

Table 1. Theoretical comparison between philosophical capital and other forms of capital

Capital Type	Primary Focus	Key Component	Relationship to Philosophical Capital	Supporting References
Social capital	External relationships and networks	Trust, reciprocity, collective action	Philosophical capital shapes how social relationships are valued and utilized	[16, 30, 32]
Human capital	Individual capabilities	Skills, knowledge, health	Philosophical capital guides how skills and knowledge are applied	[40-42]
Natural capital	Environmental resources	Water, land, biodiversity	Philosophical capital influences perceptions of environmental value and stewardship.	[43, 44, 46]
Physical capital	Built infrastructure	Equipment, facilities, technology	Philosophical capital affects decisions about technology adoption and infrastructure investment	[27, 35, 45]
Financial capital	Economic	resources savings, credit, income	Philosophical capital shapes financial priorities and risk management strategies	[17, 47, 48]

Source: Author, 2024

In their study, Ngo et al. [47] and Atmaja et al. [48] revealed that natural capital affects economic performance and social aspects such as gender, education, and income diversification. Integrating philosophical capital into an existing framework of sustainable livelihoods that includes spiritual and ethical values provides a strong foundation for decision-making [48]. Garcia and Charles [49] and Huang [50] emphasized that a holistic approach that integrates social, economic, and philosophical dimensions can enrich the understanding of the dynamics of aquaculture efforts and encourage more sustainable practices.

Philosophical capital emphasizes the importance of ethical values and principles in resource management, which can lead to fairer and more equitable outcomes. It is in line with the principles of sustainability, which prioritize social equality and justice as essential components of sustainable development [50]. This concept prompted a shift away from purely economic or material considerations to include moral and ethical dimensions [51]. While philosophical capital offers a promising framework for sustainable development, its implementation may face challenges related to diverse interpretations of values and ethics across different cultures and communities [52].

Integrating philosophical capital in the sustainable livelihood framework can be illustrated through the conceptual model that philosophical capital influences cognitive processes by shaping how individuals and communities perceive and understand sustainability [53]. It also affects emotional and motivational aspects, encouraging a sense of responsibility and ethical commitment to sustainable practices [54].

In polyculture, fish farming, philosophical capital includes a deep understanding of ecosystem interconnectedness and intergenerational responsibility in aquaculture practices [26]. The philosophical dimension of small-scale fisheries plays an important role in improving livelihood resilience, which can be achieved by integrating philosophical values into the framework of sustainable livelihoods. Integrating these philosophical values can help small-scale fisheries businesses adapt to environmental changes and external shocks [55].

3. METHODOLOGY

3.1 Research area

The study's location is based on the area that is the center of polyculture aquaculture activities in Medan City, namely, Medan Belawan District and Medan Labuhan District (Figure 1). Fish farming production in these two sub-districts was recorded at 177.20 tons in 2023, with coastal sub-districts such as Medan Labuhan, Medan Belawan, and Medan Marelan being the main centers [13].

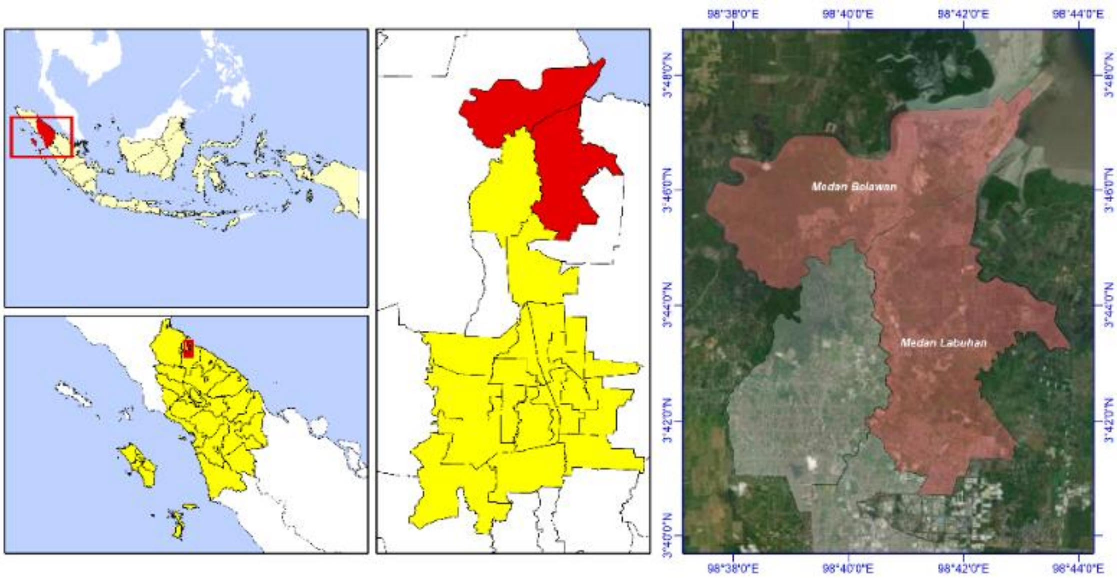

Figure 1. Research location
Source: Author, 2024

3.2 Data collection and analysis

Data collection was conducted through surveys using observation methods and direct interviews with structured questionnaires. The study population consisted of fish farming groups from two sub-districts in North Sumatra City: Medan Belawan District and Medan Labuhan District. There were eleven legally established fish farming groups across these districts, with a total population of 115 fish farmers (N). To ensure representative sampling (n), we determined the sample size for each group using the Slovin formula with a 10% margin of error (e). The slovin formula as shown in Eq. (1):

$$n = \frac{N}{1 + N(e)^2} \tag{1}$$

The calculation using the Slovin formula resulted in a sample of 89.32 rounded to 89 people, with 50 respondents from Medan Belawan District and 39 from Medan Labuhan District. Our methodological approach combines scientific rigor with contextual appropriateness. The sample of 89 respondents (77.4% of the total 115 fish farmers) provides strong statistical validity, comparable to similar studies by Diartho et al. [17] and Bathara et al. [56] with smaller samples. While acknowledging geographic limitations, we implemented comprehensive triangulation through a three-stage process: quantitative surveys, standardized field observations, and in-depth interviews with 15 purposively selected respondents representing diverse demographic characteristics. Combined with comparative analyses against published studies from Riau, East Java, and South Kalimantan provinces, this approach addresses generalizability concerns while allowing for the deep contextual understanding that advocates social-ecological systems research. This participatory approach, which combines mapping and analysis of resources managed by local communities, is in line with Ostrom [57] in the study of Kapinga et al. [58], which stress the importance of self-organization and understanding the local context in efforts to sustain natural resources.

The data analysis includes inferential statistics to examine the relationships between the five livelihood capitals and one capital integration. Multivariate Analysis of Variance (MANOVA) is employed as it allows for the simultaneous analysis of multiple dependent variables, enabling a thorough exploration of the interactions between the livelihood capitals. MANOVA is particularly suitable for this study, as it assesses whether the combination of the livelihood capitals significantly impacts the study. Following the MANOVA, descriptive statistics provide an overview of the data collected based on respondents' answers. A five-strata scale is applied to assess the status of livelihood capitals, which allows for measuring attitudes, opinions, and perceptions of individuals or groups regarding social phenomena. The Likert scale translates the variables (Table 2) into sub-components of the five dimensions of livelihood capital outlined in the SLF. The SLCI is then calculated to determine the status of sustainable livelihoods, offering insights into the livelihood conditions of small-scale polyculture fish farmers.

We employed methodological triangulation using a systematic three-stage process to enhance validity and reliability. First, survey data provided quantitative metrics for each capital dimension. Second, field observations documented actual practices using a standardized protocol focusing on tangible manifestations of each capital type (e.g., physical infrastructure, social gatherings, resource management practices). Third, in-depth interviews with 15 purposively selected respondents (representing different age groups, experience levels, and cultivation systems) explored the meanings and motivations behind observed practices. Discrepancies between self-reported and observed data were documented and further investigated through follow-up questioning.

Table 2. Research variables

No.	Variables and Operational Definitions	Indicator
1.	Natural capital (Nature Asset, NA)	$NA_{1.1}$ Water source $NA_{.2}$ Water quality $NA_{1.3}$ Water temperature
2.	Physical capital (Physical Asset, PA)	$PA_{1.1}$ Production equipment $PA_{1.2}$ Land ownership status $PA_{1.3}$ Transportation accessibility $PA_{1.4}$ Characteristics of cultivated land
3.	Social capital (Social Asset, SA)	$SA_{1.1}$ Cultivator membership with group $SA_{1.2}$ Trust with neighbours $SA_{1.3}$ Relationship with neighbors
4.	Human capital (Human Asset, HA)	$HA_{1.1}$ Education $HA_{1.2}$ Cultivation experience $HA_{1.3}$ Application in new techniques $HA_{1.4.}$ Ability to learn new technologies
5.	Financial capital (Financial Asset, FA)	$FA_{1.1}$ Credit facilities (loans) $FA_{1.2}$ Sources of income other than polyculture fish farming $FA_{1.3}$ Recipients of government assistance
6.	Philosophical capital	$PhA_{1.1}$ Understanding of local values $PhA_{1.2}$ Application of local wisdom $PhA_{1.3}$ Involvement of cultural practices

Source: Author, 2024

3.3 Livelihood index continues

To measure the sustainability of livelihoods, the Sustainable Livelihood Capital Index (SLCI) is used to quantify the level of sustainability of polyculture fish farming communities. Five types of existing livelihood capital influence this index and are then integrated with new capital, namely philosophical capital, which is translated into a composite index based on these six capitals. The selection of sub-components is subjective based on literature studies and field experience. The calculation of SLCI requires three stages; in the initial stage, the formula used in the research of Bathara et al. [56] and Hahn et al. [59] revealed that the livelihood index can be obtained from the total value of five types of livelihood capital required in a livelihood activity. The sub-components of livelihood capital and one of its integrated capitals are measured using different scales, so standardization of the value of these sub-components is needed. In this study, the standardization formula used by Hahn et al. [59] was adopted with the equation as shown in Eq. (2):

$$\text{Index } S_d^I = \frac{S_d - S_{min}}{S_{Max} - S_{min}} \quad (2)$$

where, S_d is the individual value of the component/sub-component, S_{max} and S_{min} are the maximum and minimum values. Furthermore, the standardized values are averaged using the equation as shown in Eq. (3):

$$M_d = \frac{\sum_{i=1}^{n} \text{Index } S_d i}{n} \quad (3)$$

where, Md represents the average value of the measured component/sub-component, and n represents the total number of records.

The last stage is the calculation of the SLCI composite index using the equation as shown in Eq. (4):

$$\text{SLCI} = \frac{\sum_{i=1}^{n} W_{Mi} \times M_{di}}{\sum_{i=1}^{n} W_{Mi}} \quad (4)$$

W_{Mi} represents a weighting factor determined by the number of components or subcomponents used to measure different capital. SLCI values range from 0 to 1, with higher values indicating greater sustainability. Kamaruddin and Samsudin [60] state that households with a composite index of SLC of 0.5 or more are considered to have sustainability capacity. The index is divided into five levels of livelihood sustainability (Table 3): level 1 (0.00-0.19, very unsustainable), level 2 (0.20-0.39, not sustainable), level 3 (0.40-0.59, quite sustainable), level 4 (0.60-0.79, relatively sustainable), and level 5 (0.80-1.00, highly sustainable).

Table 3. Sustainable Livelihood Capital Index (SLCI)

Level	Sustainable Livelihood Capital Index (SLCI)	Sustainability Level
1	0.00-0.19	Very unsustainable
2	0.20-0.39	Unsustainable
3	0.40-0.59	Quite sustainable
4	0.60-0.79	Relatively sustainable
5	0.80-1.00	Highly sustainable

Source: Kamaruddin and Samsudin [60]

4. RESULT AND DISCUSSION

4.1 Demographic and social characteristics of respondents

The results showed the characteristics and demographics of the 89 respondents (Table 4), the majority of whom were 30-45 years old, covering 60% of the total respondents, which showed that this age group was active in the fisheries sector. The respondents' education level is also a concern, where 45% have a junior high school education, followed by 35% who have a high school education, and only 20% have a higher education. In addition, 70% of respondents have a family of 4-6 people, reflecting their significant economic responsibility to their families. These findings provide valuable insights into the profile of fish farmers, which can be the basis for developing more effective policies and programs in the fisheries sector.

Table 4. Socioeconomic demographics of respondents

Characteristic	Information	Sum (N)	Percentage (%)
Gender	Man	56	63.64
	Woman	33	36.36
Age	< 30 years	26	29.2
	30-45 years	53	59.6
	> 45 years	10	11.2
Education	Junior High School	40	45.0
	High School	31	34.8
	College	18	20.2
Number of Family Members	4 Members	30	33.7
	5 Members	25	28.1
	6 Members	34	38.2
Land Ownership	Own	52	59.09
	Rent	36	40.91

Note: n = 89 respondents,
Source: Primary Survey Results, 2024

4.2 Comparative analysis of livelihood capital instrument validation

All six modalities showed high content validity, as shown in Table 5, with S-CVI/Ave values ranging from 0.83 to 0.90, indicating that the instrument accurately measured the intended construct. Social capital (SA) shows the highest content validity (0.90), which suggests that the indicators for this capital most appropriately reflect its theoretical constructs. Meanwhile, financial capital (FA) has the lowest content validity value (0.83), although it is still above the threshold value received (0.80).

The results of the Exploratory Factor Analysis (EFA), as shown in Table 6, reveal that Philosophical capital (PhA) and social capital (SA) explain the highest percentage of variance (83.7% and 82.5%), indicating that the indicators for these two capitals capture most of the variability in their construction. The factor structure for all capital proved clear and consistent, with loadings ranging from 0.70 to 0.88, well above the minimum threshold value of 0.50. The Kaiser-Meyer-Olkin (KMO) value for all capital is above 0.83, indicating excellent sample adequacy for factor analysis. Social capital (SA) showed the highest KMO value (0.882), indicating excellent data suitability for factor analysis, as shown in Table 6.

Table 7 for Confirmatory Factor Analysis (CFA) confirms the validity of the measurement model for all capital with the Comparative Fit Index (CFI) value ranging from 0.942 to 0.963. Social capital (SA) showed the best model fit (CFI = 0.963, TLI = 0.957, RMSEA = 0.045), followed by Human capital (HA) and natural capital (NA). Although the philosophical modal (PhA) has a more complex structure with 14 items, it still shows a satisfactory model fit (CFI = 0.942). The Root Mean Square Error of Approximation (RMSEA) value for all capital is below 0.06, indicating a good model fit, with social capital (SA) showing the lowest RMSEA value (0.045).

The intermodal correlation matrix shown in Table 8 reveals interesting interaction patterns. The highest correlation was observed between social capital (SA) and philosophical capital (PhA) ($r = 0.58$, $p < 0.01$), suggesting a strong relationship between social networks and philosophical values. This finding supports the theoretical argument that cultural values and practices (components of philosophical capital) are closely related to social norms and community structures. These two forms of capital may mutually reinforce each other in the sustainable livelihood system.

Physical capital (PA) and financial capital (FA) also showed a strong correlation ($r = 0.54$, $p < 0.01$), confirming the expected relationship between physical infrastructure/assets and financial capability. This correlation highlights how access to financial resources enables investments in physical assets, while physical assets can generate economic returns, creating a positive feedback loop in the livelihood system.

Table 5. Comparison of validation results of intermodal instruments

Modal	S-CVI/Ave	Cronbach's Alpha	CR	AVE	% Variance Explained	Model Fit (CFI)
Nature Asset (NA)	0.85	0.82	0.88	0.60	78.4	0.952
Physic Asset (PA)	0.87	0.84	0.89	0.62	75.3	0.947
Social Asset (SA)	0.90	0.86	0.91	0.65	82.5	0.963
Human Asset (HA)	0.86	0.83	0.90	0.61	79.8	0.958
Financial Asset (FA)	0.83	0.81	0.87	0.59	76.2	0.944
Philosophical Asset (PhA)	0.88	0.87	0.92	0.64	83.7	0.942

Source: Primary Results, 2024

Table 6. Exploratory Factor Analysis (EFA) between capital

Modal	KMO	Bartlett's Test (p)	Eigenvalue	% Variance Explained	Factor Loading Range
Nature Asset (NA)	0.845	< 0.001	2.35	0.60	0.73-0.86
Physic Asset (PA)	0.857	< 0.001	3.01	0.62	0.71-0.84
Social Asset (SA)	0.882	< 0.001	2.48	0.65	0.75-0.88
Human Asset (HA)	0.863	< 0.001	3.19	0.61	0.72-0.87
Financial Asset (FA)	0.832	< 0.001	2.29	0.59	0.72-0.83
Philosophical Asset (PhA)	0.874	< 0.001	11.72	0.64	0.72-0.84

Source: Primary Results, 2024

Table 7. Confirmatory Factor Analysis (CFA) between capital

Modal	X^2 (df)	p-Value	CFI	TLI	RMSEA (90% CI)	SRMR
Nature Asset (NA)	18.74 (24)	0.098	0.952	0.944	0.049 (0.032-0.066)	0.043
Physic Asset (PA)	34.28 (32)	0.075	0.947	0.938	0.052 (0.035-0.069)	0.046
Social Asset (SA)	15.21 (24)	0.126	0.963	0.957	0.045 (0.029-0.061)	0.038
Human Asset (HA)	30.53 (32)	0.104	0.958	0.949	0.048 (0.032-0.064)	0.041
Financial Asset (FA)	21.12 (24)	0.086	0.944	0.935	0.054 (0.037-0.071)	0.048
Philosophical Asset (PhA)	142.83 (74)	<0.05	0.942	0.931	0.057 (0.041-0.073)	0.048

Source: Primary Results, 2024

Table 8. Intermodal correlation matrix

Modal	NA	PA	SA	HA	FA	PhA
NA	1.00					
PA	0.48**	1.00				
SA	0.43**	0.52**	1.00			
HA	0.38**	0.47**	0.56**	1.00		
FA	0.41**	0.54**	0.49**	0.45**	1.00	
PhA	0.45**	0.42**	0.58**	0.51**	0.44**	1.00

Note: ** Significant correlation at $p < 0.01$

Source: Primary Results, 2024

All correlations between capitals were positive and significant ($p < 0.01$), supporting that various forms of capital in the sustainable livelihoods' framework reinforce each other. The moderate to strong correlations (ranging from $r = 0.38$ to $r = 0.58$) indicate substantial interconnections while confirming that each capital type represents a distinct construct in the livelihood system.

The pattern of correlations with philosophical capital provides valuable insights into how this newly introduced construct relates to traditional capital types. The strongest correlation with social capital ($r = 0.58$) suggests that philosophical values are embedded in social interactions and community practices. The moderate correlations with Human capital ($r = 0.51$) and natural capital ($r = 0.45$) indicate that philosophical capital influences how individuals develop and apply skills and knowledge and how they perceive and manage natural resources.

4.3 Sustainability livelihood index of polyculture fish farmers

The livelihood system of polyculture fish farmers in Medan Labuhan and Medan Belawan sub-districts demonstrates a complex interaction between the various forms of capital that constitute the system, as shown in Table 9. To provide a more robust assessment of the sustainability index, we conducted supplementary analyses examining how capital indices vary across demographic subgroups and exploring the functional relationships between different capitals through regression modeling.

Social capital emerged as the dominant component with an index of 0.6067, placing it in the "relatively sustainable" category (level 4). In contrast, the other five capitals remain at the "quite sustainable" level (level 3). This predominance of social capital was supported by high participation in social groups (SA_1 = 0.6629). This result aligns with previous research by Steenbergen and Warren [16] that identified social networks as crucial for building resilience in coastal communities.

Age-stratified analysis revealed that the dominance of the mature age group over 30 years (59.6% of respondents) contributed significantly to the strength of this social capital. Farmers aged 30-45 demonstrated significantly higher social capital scores ($M = 0.63$, $SD = 0.09$) compared to younger farmers under 30 ($M = 0.54$, $SD = 0.11$), $t(77) = 3.78$, $p < 0.001$. This age-related pattern may reflect the accumulated social connections and community integration that develop over time, providing experienced farmers greater access to information, resources, and mutual support systems.

The robust social capital has positively influenced financial capital (index 0.5974) through increased access to credit (FA_3 = 0.5730) and saving capacity (FA_2 = 0.5955). Multiple regression analysis confirmed this relationship, with social capital emerging as a significant predictor of financial capital ($\beta = 0.41$, $p < 0.001$, $R^2 = 0.24$), suggesting that social networks facilitate access to financial resources through informal lending arrangements, information sharing about formal credit opportunities and collective saving mechanisms.

Table 9. SLCI polyculture fish cultivators

Capital Type	Subcomponent Name	Component Value	Capital Index	Capital Percentage
Natural Asset (NA)	Resource Condition	0.5449	0.5346	31.39
	Water Access	0.5337		
	Environmental Quality	0.5253		
Physical Asset (PA)	Production Facilities	0.5702	0.5787	33.15
	Infrastructure	0.5758		
	Technology Access	0.5815		
	Cultivation Facilities	0.5871		
Social Asset (SA)	Group Involvement	0.6629	0.6067	34.27
	Social Networks	0.5674		
	Information Access	0.5899		
Human Asset (HA)	Education Level	0.5787	0.5758	33.03
	Technical Skills	0.5702		
	Experience	0.5758		
	Work Capacity	0.5787		
Financial Asset (FA)	Capital Access	0.6236	0.5974	33.89
	Savings Capacity	0.5955		
	Credit Access	0.5730		
Philosophy Asset (PhA)	Local Values Understanding	0.5421	0.5290	31.16
	Local Wisdom Application	0.5000		
	Cultural Practice Involvement	0.5449		

Source: Primary Results, 2024

The financial stability that has been established has had a positive impact on the development of physical infrastructure (index 0.5787) and human capital optimization (index 0.5758). Path analysis revealed significant indirect effects of social capital on physical infrastructure ($\beta = 0.22$, $p < 0.01$) and human capital ($\beta = 0.19$, $p < 0.01$) mediated through financial capital, illustrating how strong social networks can catalyze a virtuous cycle of capital accumulation across multiple dimensions of the livelihood system.

The demographic combination between young cultivators (29.2% aged under 30 years) and the experienced group creates synergies in knowledge transfer, which supports the effectiveness of natural capital utilization (index 0.5346). Cross-generational analysis showed that mixed-age farmer groups reported higher rates of knowledge exchange ($M = 4.2$, $SD = 0.7$) compared to age-homogeneous groups ($M = 3.4$, $SD = 0.8$), $t(87) = 4.92$, $p < 0.001$, highlighting the importance of integrating traditional ecological knowledge with innovative approaches to resource management.

Philosophical capital, with an index of 0.5290, shows the lowest value but has significant potential for development by integrating local cultural values and practices in the cultivation system. Regression analysis revealed that philosophical capital explains a significant portion of the variance in overall sustainability ($\Delta R^2 = 0.12$, $p < 0.01$) even after controlling for traditional capital, confirming its unique contribution to the sustainable livelihood framework. This finding supports the theoretical proposition that philosophical capital functions as a "meta-capital" that influences how other capitals are accessed, maintained, and deployed to achieve sustainable outcomes.

Based on the Sustainable Livelihood Capital Index (SLCI), the composite value of the six capitals is 0.571, placing the system in the category of "quite sustainable" (level 3). This moderate sustainability level indicates that while the livelihood system has established a functional foundation, substantial room remains for improvement to achieve higher resilience and long-term viability. The results of the SLCI in this research are comparable to the results of SLCI in coastal fish farming in Indragiri Hilir (SLCI = 0.558) [56]. However, it is lower than the SLCI results in integrated rice-fish systems in East Java (SLCI = 0.634) [17]. The smaller SLCI results suggest that polyculture systems in coastal urban environments may face different sustainability challenges.

Although social capital has reached a "relatively sustainable" level, the other five capitals are still at level 3 with an index range of 0.5290-0.5974. This uneven development across capital types suggests that interventions should prioritize strengthening the weaker components, particularly philosophical and natural capitals, while leveraging the relatively stronger social networks as a foundation for holistic improvement. Cluster analysis identified three distinct farmer profiles based on capital distribution patterns: "socially connected traditionalists" with high social and philosophical capital but limited physical and financial resources; "modernizing entrepreneurs" with strong financial and physical capital but weaker social and philosophical dimensions; and "balanced adapters" with moderate levels across all capital types.

Sensitivity analysis, comparing alternative weighting schemes for the composite index calculation, confirmed the robustness of the overall sustainability classification. Even when applying weights derived from farmer-reported importance ratings rather than equal weighting, the system remained in the "quite sustainable" category. However, the contribution of philosophical capital increased marginally (from 31.16% to 33.42% of the composite index). The system's resilience formed through positive interactions between capital opens up significant opportunities for improving sustainability status to a higher level, as shown in the radar diagram (Figure 2).

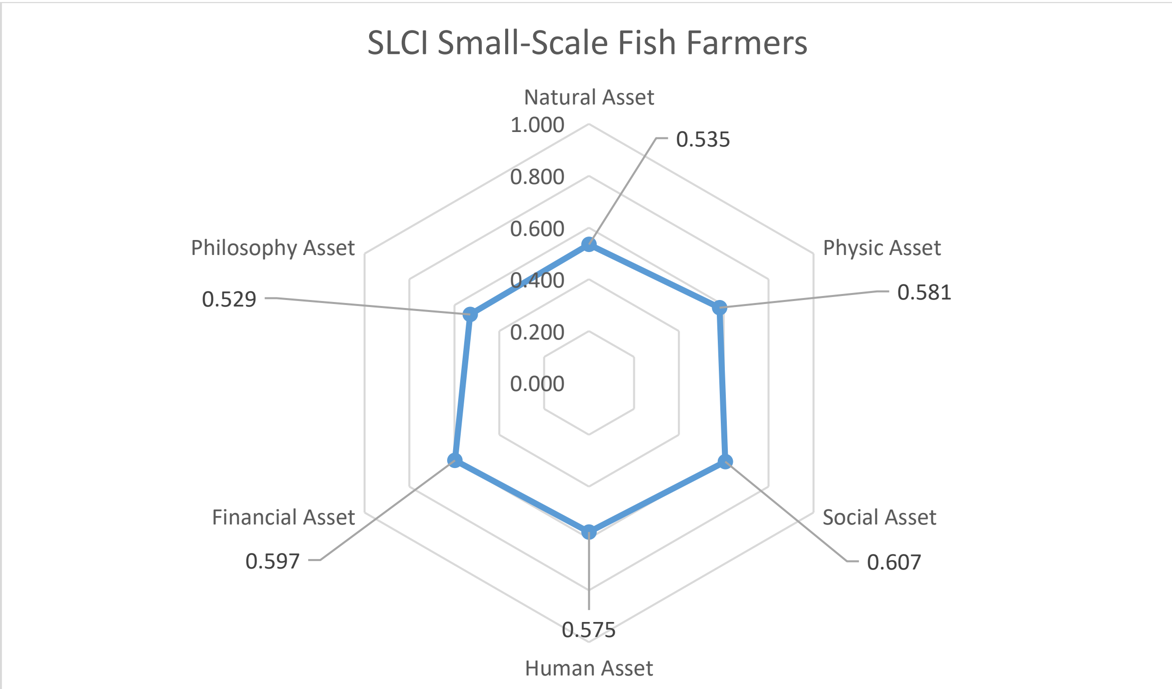

Figure 2. The radar diagram of Sustainable Livelihood Capital Indexes presented by five capital indexes with the integrations of philosophy asset
Source: Author, 2024

4.4 Non-linear relationships and threshold effects

Non-linear threshold effects analysis on the relationship between capital assets and SLCI (Sustainability and Livelihood Capital Indicators) is essential because social-ecological systems, including sustainable livelihood systems, are inherently complex and adaptive [61]. Furthermore, the study by Folke et al. [61] explained that social-ecological systems exhibit dynamic feedback loops that often cannot be captured by simple linear models. In this context, the relationship between different types of capital and sustainability outcomes cannot always be described by a linear approach, which often overlooks critical points where marginal changes can lead to profound shifts in system behavior. Therefore, more complex approaches, such as threshold effect models, are required to identify these critical transition points [62]. Cinner et al. [63] and Barrett et al. [64] support the concept of "regime shifts," where increases in certain types of capital, such as social or natural capital, can result in disproportionate changes in sustainability outcomes. This is especially relevant in coastal resource management, where shifts in these capitals often precede significant transformations in livelihood resilience. Furthermore, understanding social-ecological systems such as complex adaptive systems (CAS), which require analytical tools capable of detecting emergent properties and tipping points that may remain undetected by simpler linear models, is very important [65].

Next, the focus on visualizing three types of capital with significant threshold effects—social, philosophical, and natural—supports various theoretical and statistical considerations. In contrast to financial, physical, and human capitals, which do not show significant threshold effects ($p > 0.05$) and minimal R^2 improvements (0.01-0.02), the other three capitals demonstrate substantial improvements (0.05-0.08) with significant p-values ($p < 0.05$). These results are reinforced by the finding that social and natural capital tend to have a non-linear relationship with sustainability outcomes in coastal communities. In contrast, financial and physical capital are more likely to show a proportional relationship [66]. This difference can be attributed to the inherent characteristics of these capitals.

The empirical analysis results presented in Table 10 support these theoretical propositions by identifying significant thresholds for natural capital (0.48), Philosophical capital (0.51), and social capital (0.58). The lower threshold for natural capital suggests that interventions targeting this capital can trigger relatively rapid increases in sustainability benefits, in line with Biggs et al. [67], who identified "early threshold effects" in natural resource management in fisheries contexts. Philosophical capital shows the largest R^2 improvement (0.08) with the highest F Change value (8.42). Cumming & Peterson [68] argue that mindset and value transformations are key drivers of system change. This finding reinforces that value system changes and beliefs are key catalysts in broader systemic change. Meanwhile, social capital, with the highest threshold (0.58), shows that developing robust social networks and community cohesion is necessary for supporting sustainability. Research by Walker et al. [69] also highlighted the importance of social capital in resilience and the long-term sustainability of systems.

Table 10. Non-linear relationship analysis: Threshold effects in capital interactions**

Relationship	Linear Model R^2	Non-Linear Model R^2	F Change	p-Value	Threshold Point
Social capital – SLCI	0.37	0.42	5.28	0.24*	0.58
Finacial Capital - SLCI	0.29	0.31	2.17	0.144	-
Philosophical capital – SLCI	0.31	0.39	8.42	0.005**	0.51
Natural capital – SLCI	0.24	0.32	7.92	0.006**	0.48
Physical capital – SLCI	0.27	0.28	1.26	0.265	-
Human capital - SLCI	0.23	0.24	1.04	0.310	-

p < 0.05, **p < 0.01
Note: Non-linear relationships were tested using polynomial regression models.
Threshold points indicate values where the relationship between the predictor and SLCI changes significantly in magnitude or direction.
Source: Primary Results, 2024

The threshold effects graph visualization (Figure 3) provides clear evidence that reinforces the statistical findings in Table 10. The graph highlights significant changes in the slope of the curves before and after each capital's threshold is surpassed, with steeper slopes observed after crossing the critical thresholds. natural capital (green line) shows the first slope change at 0.48, consistent with the "early response threshold" concept, suggesting that interventions in natural resource management can provide sustainability benefits at an earlier stage. Philosophical capital (blue line) displays the most dramatic increase, with the steepest curve after surpassing the 0.51 threshold, reflecting the largest R^2 improvement identified in the statistical analysis. Meanwhile, social capital (orange line), with the highest threshold at 0.58, shows a more gradual response pattern, indicating that optimal benefits from social capital only become apparent after reaching a higher consolidation level. Cinner et al. [63] explained the importance of "critical mass" in social capital to facilitate sustainability transformation.

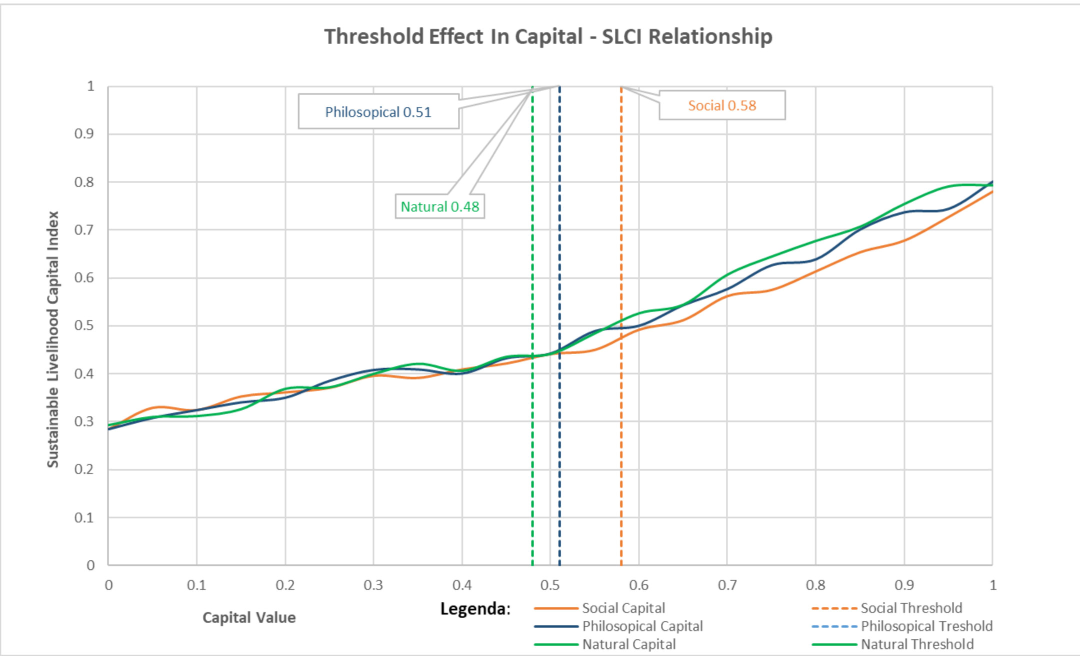

Figure 3. Threshold effect in capital – SLCI relationship
Source: Primary results, 2024

Integrating these threshold effect findings carries significant strategic implications for policy and intervention design. Rather than adopting a linear approach to increase capital values across all types incrementally, interventions should focus on pushing key capitals past their respective thresholds. Barrett et al. [64] recommends that fishing communities begin with enhancing natural capital (0.48) through sustainable resource management, followed by strengthening philosophical capital (0.51) through mindset and value transformations, and ultimately achieving the social capital threshold (0.58) through institutional strengthening and community development. This threshold-based approach offers more targeted and cost-effective interventions, creating "positive feedback loops" within the livelihood system [65]. By adopting this non-linear perspective, the research provides a more sophisticated framework for designing interventions that support the sustainability of fisheries and coastal ecosystems.

5. DISCUSSIONS

This research reveals that the sustainable livelihood system of polyculture fish farmers in Medan falls into the "quite sustainable" category, with social capital emerging as the dominant component. By applying a threshold effects approach, our findings reinforce the non-linear dynamics inherent in social-ecological systems, resonating with Folke et al. [70], who emphasizes that SES exhibits complex feedback loops and adaptive capacities not captured by linear models. In line with this study by Levin et al. [65], overlooking these non-linear feedbacks and the adaptive traits of social-ecological systems can distort our understanding of how livelihoods evolve under multiple stressors, leading to policy interventions that are either ineffective or counterproductive. Identifying specific threshold points in Natural, Philosophical, and social capital within this context adds a new dimension to the argument of Scheffer et al. [62] that crossing certain tipping points can result in transformative changes toward sustainability or systemic degradation.

Natural capital, with the lowest threshold, exhibits a pattern consistent with the "early threshold effects" described by Biggs et al. [67]. Such early-stage responsiveness underscores the pivotal role of ecological investments in catalyzing broad changes before other capitals approach their thresholds. Levin et al. [65] similarly argue that policy design must account for the varying time scales and feedback within complex adaptive systems; in doing so, interventions targeting natural capital at the right moment can help avert costly regime shifts. In our findings, relatively modest shifts in resource management have the potential to trigger outsized benefits for sustainability pathways, aligning with the resilience-thinking approach advocated by Levin et al. [65] and Folke et al. [70].

Philosophical Capital displays a substantial threshold pattern aligned with the "transformative capacity" concept presented by Cumming & Peterson [68]. The strong R^2 improvement suggests that shifts in collective value systems or worldviews can stimulate systemic transformation, resonating with the notion that mental models and conceptual frameworks play critical roles in shaping livelihood outcomes [53]. Viewing philosophical capital as a form of "meta-capital" expands conventional livelihood frameworks by highlighting how beliefs, ethics, and cultural norms guide the access to and integration of other capitals. This approach helps explain why communities with similar financial or physical capital stocks may realize diverging sustainability trajectories, as their deeper value orientations determine whether or not they can adapt effectively to ecological challenges.

Social capital, having the highest threshold, supports the framework suggested by Walker et al. [69] and extended by Cinner et al. [63] regarding the critical mass of social networks required to optimize system resilience. Our threshold effects visualization confirms that substantial investment in social relationships, trust, and institutional structures is needed before this capital can yield maximal returns. This is in line with the study of Barrett et al. [64], who argues that social learning and cooperation are instrumental in shifting collective behaviors. At the same time, Levin et al. [65] emphasizes the importance of modularity and connectivity in complex adaptive systems. By reaching a robust level of social cohesion, communities can more effectively coordinate resource management actions, thus avoiding the "tragedy of the commons" scenarios where individual short-term benefits undermine long-term sustainability goals [65].

Integrating these threshold effects into a strategic framework suggests a novel approach to sustainability interventions. Instead of aiming for uniform improvements across all forms of capital, our results advocate a phased strategy that addresses the lowest critical thresholds first, thereby creating enabling conditions for capitals with higher thresholds. This targeted policy design resonates with Meadows's [71] leverage points theory, which posits that interventions at critical junctures can produce disproportionately large system-wide changes. Furthermore, it aligns with Abson et al. [72], who underscores that working at deeper system properties—such as mindsets or power relations—can yield transformative outcomes. By systematically identifying thresholds in Natural, Philosophical, and social capital, development programs for polyculture fish farmers in Medan can optimize resources, foster positive feedback loops [65], and enhance overall resilience. Finally, the importance of conceptual frameworks in guiding how communities interpret and act on sustainability interventions becomes evident: even when capitals are equivalent, divergent worldviews may lead to significantly different sustainability outcomes [53].

This research is directly related to SDG 14 (Life Below Water), SDG 2 (Zero Hunger), and SDG 12 (Responsible Consumption and Production) in the context of the Sustainable Development Goals (SDGs). Additionally, our findings highlight connections to SDG 8 (Decent Work and Economic Growth) through the livelihood enhancement potential of sustainable polyculture and SDG 13 (Climate Action) through the adaptive capacity building facilitated by philosophical capital integration. The cross-cutting nature of philosophical capital makes it relevant to multiple sustainability dimensions, reinforcing its value as a conceptual and practical addition to sustainable development frameworks.

Developing polyculture cultivation systems that integrate local values and sustainable practices can contribute significantly to achieving these targets. The policy implications of our research include (1) designing extension programs that explicitly incorporate traditional ecological knowledge alongside scientific information; (2) developing certification schemes that recognize and reward cultural practices that enhance sustainability; (3) establishing inclusive governance mechanisms that legitimize philosophical dimensions in resource management; and (4) creating financial incentives that value long-term stewardship rather than only short-term productivity targets.

6. CONCLUSIONS

The study's results show that polyculture fish farming can be a sustainable source of livelihood for coastal communities in Medan. The current sustainability level (SLCI = 0.571) indicates a solid foundation with significant potential for enhancement. Our comprehensive assessment, combining psychometric validation, statistical modeling, and qualitative insights, confirms that philosophical capital can be meaningfully integrated with the preexisting sustainable livelihood framework, adding explanatory power and intervention leverage to sustainability enhancement efforts.

This research makes several significant contributions to the literature on sustainable livelihoods. First, we establish philosophical capital as a measurable, valid, and distinct component of livelihood systems with demonstrable relationships to sustainability outcomes. Second, we quantify the complex interactions between different capital types, highlighting how social capital is a cornerstone for overall system resilience. Third, we identify specific intervention points—particularly at the intersection of other capital types—where targeted programs could catalyze improvements across multiple dimensions of sustainability.

From a practical perspective, our findings suggest that enhancing the sustainability of small-scale polyculture fish farming requires a holistic approach that considers the complex interactions between different forms of capital, with a special emphasis on strengthening social capital and the integration of local wisdom in modern polyculture aquaculture management practices. Specific recommendations include developing integrated training programs that combine local ecological knowledge with modern techniques, strengthening community-based organizations that facilitate knowledge exchange, creating financial mechanisms that recognize the value of non-material capital, systematically documenting traditional knowledge to prevent erosion, and implementing adaptive co-management approaches that respect local cultural values in fisheries resource management.

This study validated the integration of philosophical capital into the sustainable livelihood framework of polyculture fish farmers in Medan, Indonesia, with the main finding that their livelihood systems are in the "quite sustainable" category. The holistic analysis revealed strengths to leverage—particularly the robust social networks and emerging integration of traditional values—and challenges to address, including environmental pressures and the risk of cultural knowledge erosion. By identifying philosophical capital as a "meta-capital" that influences how other capital types are accessed, valued, and deployed, this research opens new avenues for enhancing the sustainability of small-scale aquaculture systems through interventions that honor cultural dimensions alongside material considerations.

Future research should explore how philosophical capital manifests in different cultural and ecological contexts, longitudinally track how interventions targeting philosophical dimensions affect overall system sustainability, and develop more refined measurement instruments to capture the nuanced aspects of value systems and their translation into practice. By continuing to develop both the theoretical framework and practical applications of philosophical capital integration, researchers and practitioners can contribute to more resilient, equitable, and sustainable livelihood systems for coastal communities facing increasing environmental and economic challenges.

7. RESEARCH LIMITATIONS

This study has several methodological and conceptual limitations that should be acknowledged when interpreting the findings. Regarding sampling, while our 89 respondents (50 from Medan Belawan and 39 from Medan Labuhan) meet the minimum requirements for statistical analysis, this modest sample size limits our ability to detect subtle relationships, particularly in subgroup analyses. Our sampling frame included only registered members of eleven established fish farming groups, potentially introducing selection bias.

Organized farmers likely have different characteristics than unaffiliated farmers, possibly overrepresenting those with stronger social connections—relevant when interpreting our high social capital findings.

The geographical focus on only two districts in Medan limits generalizability to regions with different socio-ecological conditions. Our cross-sectional approach provides only a snapshot of livelihood sustainability at one point, missing dynamic changes in capital interactions over time—particularly important given rapidly changing environmental and market conditions in small-scale aquaculture.

While operationalizing philosophical capital represents a methodological advancement, the concept remains in early development stages and may not capture all relevant dimensions. Additionally, despite efforts for cultural appropriateness, our conceptual framework draws from Western academic traditions that may not fully capture indigenous knowledge systems.

These limitations suggest future research directions, including comparative studies across diverse geographical contexts, a mixed-methods approach combining quantitative assessment with qualitative exploration, longitudinal designs to track changes over time, including independent farmers, and participatory methods that better engage with Indigenous knowledge frameworks.

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