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Agroecology principles in aquaculture: a case study of East Africa

Agroekološki principi v akvakulturi: študija primera v vzhodni Afriki

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ABSTRACT

Agroecology in East Africa is gaining momentum due to its potential benefits for food security, the environment, and climate, supported by research, policy, and economic drivers; meanwhile, Integrated Aqua-Agriculture, as one of the promising practices for agroecological transition, confronts challenges like infrastructure and expertise hurdles. The PrAEctiCe project addresses these by unveiling three distinct "Living Labs" in East Africa. In Kisumu (Kenya), the lab focuses on the synergy between aquaculture and intercropping, utilizing aquaculture wastewater for irrigation and converting aquaculture sludge into fertilizer. The Kajjansi (Uganda) lab delves into aquaponics, experimenting with varying combinations of fish and vegetables to optimize water, energy, and nutrient dynamics. In contrast, the Morogoro (Tanzania) lab integrates fish and poultry systems, utilizing fishpond wastewater for vegetable irrigation and combining aquaculture sludge with poultry manure to enrich the soil. Living Labs are designed following general agroecological principles adopted for aquaculture. By providing tangible demonstrations and fostering knowledge sharing, they contribute crucial data for the ongoing development of agroecology-tailored indicator framework for aquaculture and the decision support tool for smallholder farmers, with the goal of charting a promising agroecological path of African agriculture.

Keywords: integrated aqua-agriculture, indicator framework, living labs, decision support tool, smallholder farmers

POVZETEK

Agroekologija v Afriki pridobiva zagon zaradi potencialnih koristi za prehransko varnost, okolje in podnebje, ki jih podpirajo raziskave, politika in gospodarski dejavniki. Medtem pa se integrirana akvakultura, kot ena od obetavnih praks za agroekološki prehod, sooča z izzivi, kot so pomanjkanje infrastrukture in strokovnega znanja. Projekt PrAEctiCe na problem odgovarja z ustanovitvijo treh različnih "živih laboratorijev" v Vzhodni Afriki. V Kisumu (Kenija) se laboratorij osredotoča na sinergijo med ribogojstvom in integrirano agrikulturo, uporabo odpadne vode iz ribogojstva za namakanje in pretvarjanje usedline iz ribogojstva v gnojilo. Laboratorij Kajjansi (Uganda) se ukvarja z akvaponiko in eksperimentira z različnimi kombinacijami rib in zelenjave za optimizacijo dinamike vode, energije in hranil. Nasprotno pa laboratorij Morogoro (Tanzanija) združuje sisteme za ribe in perutnino, pri čemer uporablja odpadno vodo iz ribnikov za namakanje zelenjave in združuje usedlino iz ribogojstva s perutninskim gnojem za obogatitev tal. Živi laboratoriji so zasnovani po splošnih agroekoloških načelih, sprejetih za ribogojstvo. Z zagotavljanjem otipljivih demonstracij in spodbujanjem izmenjave znanja prispevajo ključne podatke za nadaljnji razvoj agroekološko prilagojenega okvira kazalnikov za ribogojstvo in orodja za podporo odločanju za male kmete, s ciljem začrtati obetavno agroekološko pot afriškega kmetijstva.

Ključne besede: integrirana akvakultura, okvir kazalnikov, živi laboratoriji, orodje za podporo odločanja, mali kmetje

INTRODUCTION

Agroecology is a foundational approach to sustainable agriculture in East Africa, intertwining ecological principles with agricultural practices to address the region's challenges. It is a critical transition in confronting land degradation, declining soil fertility, biodiversity loss, water scarcity, and enhancing food security and nutrition. Nations like Kenya, Tanzania, and Uganda have exhibited a shift towards agroecological practices, encouraging a move away from heavy reliance on chemical inputs and uplifting smallholder farmers' livelihoods (Mwanake et al.,2023)

Amid agricultural challenges in the region, the PrAEctiCe project is crucial for advancing agroecological practices. Its mission is twofold: addressing smallholder farmers' unique challenges and supporting their transition to agroecological farming. The initiative focuses on developing agroecology indicators tailored to East Africa. This paper explores harmonizing diverse indicators into a multilevel framework (Gliessman, 2016).

Aqua-Agriculture (IAA) is central to PrAEctiCe's focus on circular water-energy-nutrient systems, integrating aquaculture with crop and livestock farming. This circular system uses waste from one component as a resource for another, optimizing resource use and enhancing ecosystem services, contributing to agricultural sustainability and resilience (Newell et al., 2019).

PrAEctiCe will blend traditional and modern agricultural practices, utilize remote data collection via sensors and satellite data, and develop a decision support tool (DST) to assist agroecology advisors in guiding smallholder farmers. The initiative aims for scalability and sustainability, ensuring technological advancements benefit smallholder farmers.

Three living labs have been established in Kenya, Uganda, and Tanzania, serving as platforms for experimentation, innovation, and DST validation in IAA systems. These labs connect scientific expertise with local knowledge, fostering collaborative development, testing solutions, and generating critical data for research and development. They also promote public engagement and knowledge sharing.

As mentioned, the PrAEctiCe faces a crucial challenge in developing a functional agroecological indicator framework. This challenge requires creating integrated indicators that reflect farm-level realities while encompassing broader impacts at the DST, living lab, policy, regional, national, and other scales (Wiget et al., 2020).

MATERIALS AND METHODS

The PrAEctiCe methodology (Figure 1) comprises four fundamental research activities to advance agroecological practices in East Africa and is currently ongoing, with the methodology still under construction. The four fundamental research activities in the PrAEctiCe methodology are mapping agroecological practices in East Africa, developing the PrAEctiCe indicator framework, developing the PrAEctiCe decision support tool (DST), and validating the DST in living labs. The project began with an exhaustive mapping of agroecology in the area, which involved identifying the current agroecological farms and stakeholders to establish a strong foundation. The mapping exercise under the PrAEctiCE project identified 219 stakeholders engaged in agroecological (AE) practices across Kenya, Uganda, and Tanzania. The outcomes revealed a diverse array of stakeholders, including agricultural producers, research institutions, policy agencies, consumer groups, and development organisations. The most comprehended AE concepts among stakeholders were sustainable farming practices, such as production without synthetic inputs, soil conservation, biodiversity, and recycling. Key challenges identified included inadequate financing, limited market support, and resistance to change. The exercise underscored the need for capacity building, particularly in technical extension services, and highlighted the importance of co-creation and knowledge networks in promoting AE practices effectively (Gitau et al., 2023).

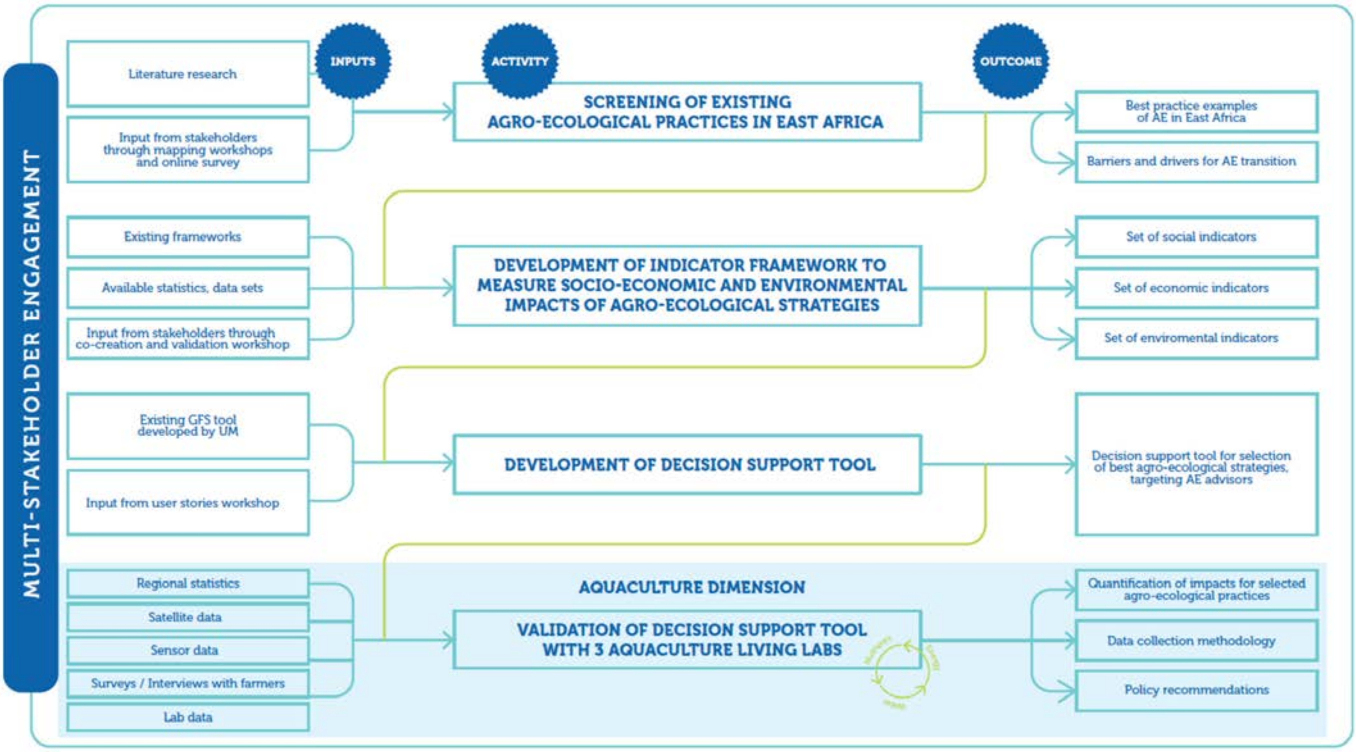

Figure 1. Concept of the PrAEctiCe methodology

The project's next phase will develop an indicator framework incorporating socio-economic and environmental indicators tailored explicitly to the East African context. Another pivotal component is the development of a DST that provides agroecology advisors and farmers with data-driven insights for informed decision-making using advanced data collection and predictive analytics. The DST's efficacy will be precisely validated within three living labs in varied climate zones, facilitating the testing and refinement of innovative methods. Living labs will be leveraged to showcase the benefits and outcomes of implementing IAA practices.

INDICATOR FRAMEWORK

The PrAEctiCe project will develop an indicator framework based on the Pressure-State-Response (PSR) model, which is designed to assess and guide the agroecological transition in East Africa (Wiget et al.,2020). The PrAEctiCe indicator framework captures the essential aspects of agroecological practices in East Africa. The objective is to select indicators representing the challenges and opportunities associated with agroecological farming practices in East Africa. The framework must consider the wide range of agricultural zones and climatic conditions across the region to ensure the indicators are relevant and adaptable to local contexts (Newell et al., 2019). In addition, it has to include specific indicators related to integrated aqua-agriculture practices, recognizing their significant contribution to the sustainability of farming systems. Lastly, the goal is for framework indicators to assess the effects of climate change mitigation and adaptation measures and evaluate smallholder farms' economic viability. The statements above serve as the foundation for the vertically interconnected framework from the farm level up to policy-making through the development of integrated indicators (Wiget et al.,2020).

DECISION SUPPORT TOOL

The decision support tool (DST), a vital component of the PrAEctiCe project, is beeing engineered to facilitate the transition of smallholder farmers in East Africa to agroecological practices by enhancing communication and decision-making between farmers and agroecology advisors. The DST integrates data from various sources, such as remote sensors and satellite imagery, incorporating predictive analytics to provide practical insights into farm management, economic viability, and environmental sustainability as shown in Figure 2 (Mongus et al., 2021). It is designed to support farmers at every stage of their agroecological journey, from adopting new practices to monitoring progress and managing farm activities, ultimately facilitating a sustainable transition. For advisors, the DST streamlines farm management, making monitoring agroecological indicators easier and developing comprehensive transition plans across multiple farms.

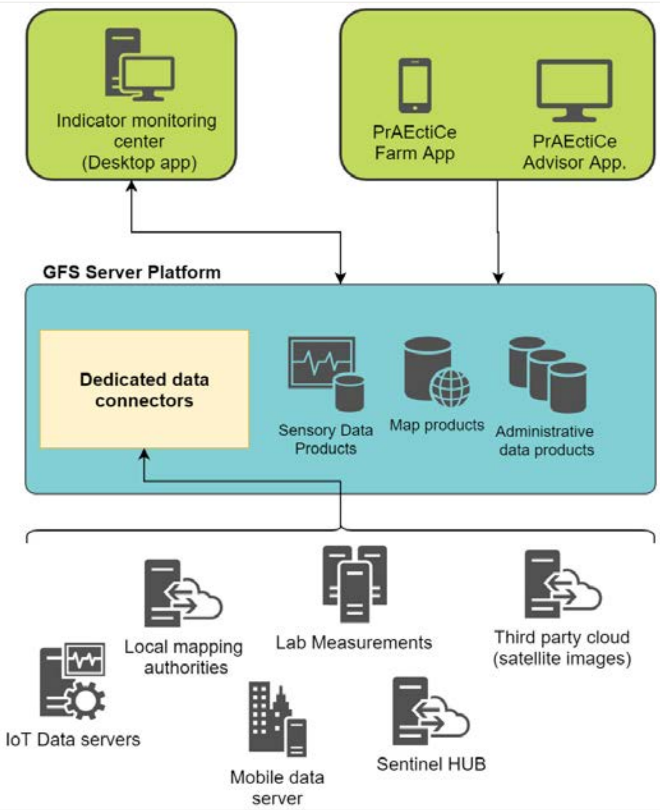

Figure 2. High-level fuctional PrAEctiCe DSS architecture (Ogello and Hoinkis, 2023)

LIVING LABS

Living lab 1: Integrated aqua-agriculture - Kisumu, Kenya

Living lab 1 is an integrated aquaculture-agriculture system shown in Figure 3. The system features advanced technologies such as a membrane bioreactor to recycle communal wastewater, floating PhotoVoltaic panels, and batteries to address power outages and minimize electricity expenses. Additionally, it recycles aquaculture sludge to enhance soil fertility and irrigate the intercropped agricultural system (Clough et al., 2020). The lab explores using black soldier flies as bio-waste converters to develop organic-based fish feed from the larvae.

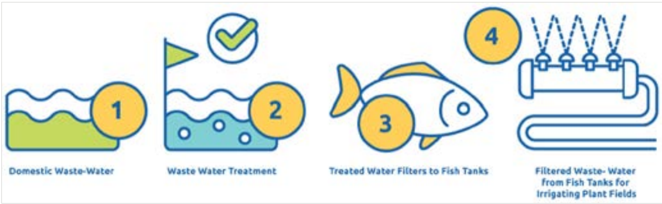

Figure 3. Scheme of IAA at Living lab 1 located in Kisumu, Kenya

Living lab 2: Aquaponics - Kajjansi, Uganda

A Living lab 2 (Figure 4) focuses on aquaponic systems tailored to the unique conditions, needs, and financial constraints of Ugandan farmers. The lab will experiment with various elements such as materials, technical equipment, environmental conditions, plant varieties, fish species, and farming techniques. The water system will be upgraded to increase the water reuse ratio, with a real-time water sensor system to monitor parameters like water flow, pH levels, and dissolved oxygen.

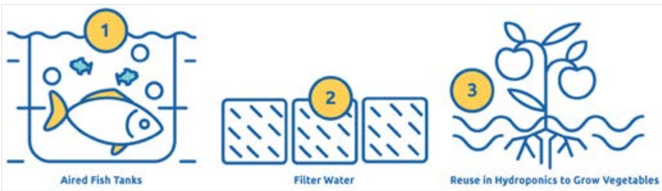

Figure 4. Scheme of the aquaponic system in Kajjansi, Uganda

Living lab 3: Fish-poultry integration system - Morogoro, Tanzania

Living lab 3 fosters an innovative integrated fish-poultry system (Figure 5). The setup includes fish ponds, a poultry unit, and vegetable production plots. Aquaculture sludge and drained water from the fish ponds will be used to irrigate and fertilize the vegetable plots, while poultry droppings will be dried and used as fish feed and fertilizer. This system aims to create sustainable and efficient food production while minimizing waste.

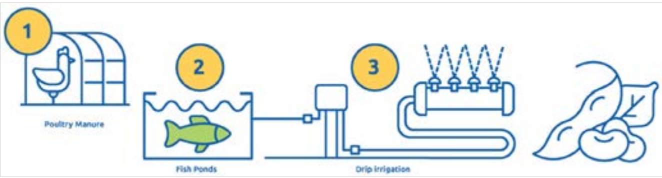

Figure 5. Scheme of Fish-poultry integration system in Morogoro, Tanzania

RESULTS AND DISCUSSION

The PrAEctiCe project navigates the complex landscape of agroecological transitions in East Africa by confronting the challenge of developing a functional and coherent agroecological indicator framework.

Addressing multilevel indicators within the PrAEctiCe project requires a detailed and nuanced approach. This method is needed because of the challenges in integrating farm-level realities with larger scales across the DST, living labs, policy, regional, national, and additional scales.

One effective solution that stands out in the literature for addressing the challenge of multilevel indicators has been the hierarchical structuring of the indicator framework, which facilitates a clear delineation of how indicators at the farm level relate to those at broader scales (Gliessmann, 2016; Mitter et al., 2019). This structuring aids in ensuring that the indicators are coherent and aligned with overarching goals in the case of PrAEctiCe, climate change mitigation, and financial viability for East African smallholder farmers.

For example, at the foundation of the PrAEctiCe framework, farm-level indicators are critical for capturing the immediate efficiencies and sustainability measures of IAA practices, including metrics on nutrient cycling, water use, crop/animal yields, and income from the practices. Ascending to the living labs level, the focus shifts towards aggregating data across multiple IAA establishments to identify regional trends, effectiveness, and areas for improvement, implementation of new technologies, and transferring knowledge to farmers with an added dimension of predicting the scalability and broader adoption of agroecological practices novel to the East African farmer. This predictive capacity is vital for understanding future challenges and opportunities in IAA scalability (Gliessman, 2016). The DST indicators build on the insights gathered from living labs and environmental data collected via satellites or sensors, facilitating strategic decisions for optimizing IAA configurations and predicting resource needs. At the apex, policy-level indicators aim to evaluate the overarching impacts of IAA practices on national food security, environmental conservation, and rural livelihoods, thereby guiding policy formulation. This hierarchical approach ensures a seamless flow of data and insights from individual farms up to the policy-making level, enabling targeted interventions and informed strategic planning for advancing IAA practices within the agroecological context (Gleissman, 2016).

The project can benefit from developing so-called integrated indicators to address this issue further. These indicators can link indicators at different levels within the framework, enhancing the framework's applicability and effectiveness across different scales (Wiget et al., 2020).

An integrated indicator is a composite metric that combines multiple individual indicators or data points from different sources or dimensions to provide a more comprehensive and holistic assessment of a specific aspect or system. Integrated indicators aim to capture the interconnectedness and complexity of various factors or variables within a system by synthesizing diverse information into a single measure or index. Furthermore, such an indicator links the multilevel indicator framework that connects different framework levels (Wiget et al., 2020).

For example, an integrated indicator for the PrAEctiCE project could be an "IAA uptake predictability index." The concept would involve forecasting the likelihood of farmers or farms adopting the technology of IAA based on specific indicators. Based on Obiero et. lab, 2018 in Kenya, aquaculture technology adoption entails identifying factors like education level, farm size, production status, attendance of extension training, and ease of technology understanding. Such an indicator could predict IAA technology uptake among farmers, aiding in targeted interventions to promote and increase the adoption of innovative technology.

Another example could be the "Resource Use Efficiency Index." This metric evaluates resource utilization in agroecological systems, focusing on water, energy, and nutrient management. It assesses water use efficiency, energy consumption, and nutrient management practices to promote sustainability (Carrasquer et al., 2017). Such an index can be devised with the potential to be implemented at either the farm or country level.

There are many possibilities for integrating specific indicators into broader integrated indicators to achieve relevance across multiple levels in the framework (Gleissman, 2016).

Furthermore, the PrAEctiCe project's methodology strongly emphasizes stakeholder engagement by involving a diverse range of individuals in developing applicable indicators for various levels and refining DST. This participatory approach has been implemented through co-creation workshops held across all three participating countries, engaging stakeholders in agroecology across multiple sectors. The PrAEctiCe project conducted a series of co-creation workshops in Kenya, Tanzania, and Uganda, engaging a diverse group of stakeholders, including farmers, financial institution representatives, government extension officers, researchers, and policymakers. These workshops were instrumental in gathering valuable feedback to refine the Decision Support Tool (DST). Key outcomes highlighted the necessity for ensuring tool sustainability post-project, enhancing user-friendliness through multi-language support and offline capabilities, and safeguarding data privacy. Additionally, the inclusion of a feedback mechanism was emphasized to facilitate continuous improvement (Ogello and Hoinkis, 2023). Through this engagement, the project will successfully ensure the relevance and acceptance of indicators at both the farm and policy levels. Co-creation workshops are a successful method for identifying and integrating actionable indicators (Wiget, 2020).

As for co-creation, continued refinement, and adaptation play crucial roles in forming a multilevel indicator framework. Agricultural systems continuously evolve; therefore, the indicator framework and DST require constant refinement. Feedback from living labs and practical implementations is crucial to incorporate into this iterative process. This process allows for the adjustment of indicators to reflect changing conditions and emerging insights objectively (Gleissman, 2016).

CONCLUSIONS

The PrAEctiCe project underscores a significant advancement in agroecological development within East Africa by innovatively integrating aquaculture and agriculture. This initiative addresses critical challenges such as food security, environmental sustainability, and economic resilience for smallholder farmers. Establishing living labs provides a hands-on platform for applying sustainable practices and facilitates knowledge transfer, broadly aiding the adoption and adaptation of these practices.

A pivotal aspect is creating a multilevel indicator framework, which is essential for understanding agroecological practices' complex impacts. This framework is fundamental for assessing the transition towards sustainable farming systems, underscoring the importance of aligning specific farm-level operations with broader environmental and socio-economic objectives. Different levels of indicators emphasize the project's complexity, and by systematizing these indicators, we gain valuable insights into the key areas requiring focus to enhance the sustainability and effectiveness of agroecological transitions.

Moreover, the project's commitment to stakeholder engagement, exemplified by co-creation workshops, showcases its dedication to collaborative innovation. This inclusive approach ensures that the technologies and practices developed are relevant and adaptable, meeting the diverse needs of the agricultural community.

The deployment of innovative tools like DST and integrated indicators represents a leap forward, offering new means to optimize resource use and predict the scalability of agroecological practices. These tools enhance decision-making for farmers and advisors, supporting PrAEctiCe's aim of facilitating a sustainable agroecological transition.

In conclusion, PrAEctiCe presents a successful model for agroecological development that marries traditional knowledge with modern technology within a collaborative, multilevel framework. Its achievements provide valuable lessons and methodologies that can be leveraged in other contexts, charting a hopeful course for sustainable agriculture worldwide.

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