Precision Aquaculture Innovation Ecosystem: A Case Study

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***Abstract* —This paper seeks to analyse the existing research on precision aquaculture developments, the ecosystem surrounding it, and its current level of adoption. Precision aquaculture refers to the use of interconnected sensors typically linked in an Internet of Things (IoT) style system to log data about aquaculture conditions to aid decision making. The utilization of sensors within an IoT framework for monitoring aquaculture conditions is highlighted as a key factor in enhancing decision-making processes. The study identifies significant challenges and proposes solutions, such as funding mechanisms and governmental support, to drive innovation and meet industry needs. Recommendations for policymakers include prioritizing funding mechanisms and knowledge dissemination to enhance global competitiveness and optimize the benefits derived from precision aquaculture technologies.**

***Keywords*—precision aquaculture, IoT, innovation ecosystem**

I. Introduction

PRECISION aquaculture involves the use of sensors to monitor the behavioural or physiological state of aquaculture stock, together with a reliable model to predict the quality and growth of stock. Measurements and predictions are then displayed in an online system to aid human decision making or provide inputs to automated controls [1]. Some key advantages of precision aquaculture include greater production efficiency through a reduction in the loss of fish fry, reduced risk of bacterial outbreaks and changes in water quality which affects the ecosystem, and a better understanding and control over fish behaviour and morphological qualities that are affected by water quality parameters [2].

Antonucci and Costa (2019) stated that areas with potential development in precision aquaculture include the use of computer vision to monitor animals, environmental monitoring tools, wireless and long range sensor networks, robotics, and tools for data interpretation and decision making. The desire to increase production, raise product quality, and address animal welfare concerns is driving the growth of precision aquaculture and engineering innovations related to it [3]. This paper aims to identify the key elements and advantages of precision aquaculture, assess the state of precision aquaculture in the Philippines, and identify opportunities for furthering precision aquaculture in the country.

II. Review of Related Literature

A. *Precision Aquaculture Description*

Føre et al (2018) described a smart aquaculture as a cyclical process of observing, interpreting, deciding, and acting on data. The process typically involves several stages, each utilizing advanced technologies. Observing often makes use of intelligent sensors and online monitoring systems. Interpreting can involve predictive models and system simulations to analyze data. Decision-making is aided by decision support systems and various forms of artificial intelligence. Finally, actions are carried out through automated actuation and integrated operations [4].

B. *Internet of Things*

IOT, also known as “Internet of Things”, is a concept of connecting to the internet with any devices. A vast network of people and connected devices makes up the IOT. Each of these gadgets collects and disseminates data about its usage and surroundings. Many things are connected to the IoT platform, including sensors-equipped devices and objects where various tools produce data that can be combined. Analytics are used to develop important information for specific needs. These dependable IoT solutions can accurately determine which information is useful and which can be safely ignored, enabling the discovery of important trends from the data obtained. The trends can then give recommendations on possible solutions for issues or even potential problems can be discovered [3].

It has been predicted that the number of IoT devices that are connected will increase by 22 billion by 2025, far from the 7 billion that we have today [6]. Industrial IoT (IIoT) refers to IoT technology used in industrial settings, particularly when it comes to instrumenting and controlling sensors and other equipment that uses cloud-based technologies [6]. Recently, industries have adopted machine-to-machine (M2M) communication, a technology that enables wireless automation and control. As cloud computing and related technologies continue to expand, industries are achieving new levels of automation. This advancement is leading to the development of new business models and income streams. The fourth wave of the industrial revolution is also known as Industry 4.0, or sometimes called IIoT. IIoT applications include many industries such as smart manufacturing, smart power grids for smart cities, digital supply chains, etc [4].

C. Precision Aquaculture Market

As a healthy protein source, seafood is increasingly popular nowadays. Precision aquaculture has changed traditional aquaculture practices and increased the aquaculture industry's productivity. The demand for protein-rich sea food and technological advancements are the main factors boosting the growth of the global precision aquaculture market, which is expected to expand at an impressive rate between 2023 and 2027 [7]. The general public's increased consumption of protein-rich foods in an effort to prevent health problems is driving up its market demand. Additionally, this preference for seafood is motivating manufacturers and producers to broaden their aquaculture platform on the international market [5].

Innovation Ecosystem Analysis Tools

Technology Roadmap

According to the Institute of Electrical and Electronics Engineers (IEEE) technology roadmaps help industry researchers and developers better understand the past, present and future of specific technologies [6].

Figure 1 below shows Phaal et al.'s (2001), framework for developing technology roadmaps. They recommend a T-Plan approach for developing roadmaps because they can be used for product planning and can easily be adapted to different industries. General guidelines they have developed include developing roadmaps that are graphical, multi-layered to reflect the interaction between technology, product, and commercial interests, and roadmaps with time dimensions clearly shown [7].

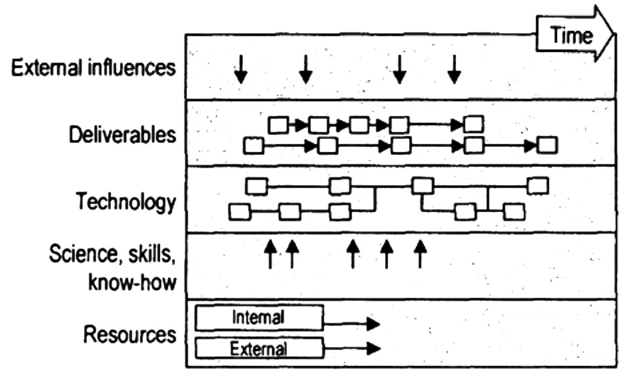

Fig. 1. Generic Technology Roadmap by EIRMA [8]

Investment Readiness Level and Technology Readiness Level

Blank (2014) provides a guideline for assessing the investment readiness level (IRL) of a technology. Figure 2 shows the framework, providing milestones that provide investors an idea of the level of maturity of a technology and how ready it is to receive and make use of more capital. Apart from aiding investors that are comparing prospective startups, it also provides guidance to researchers by providing possible next steps to mature the technology [9].

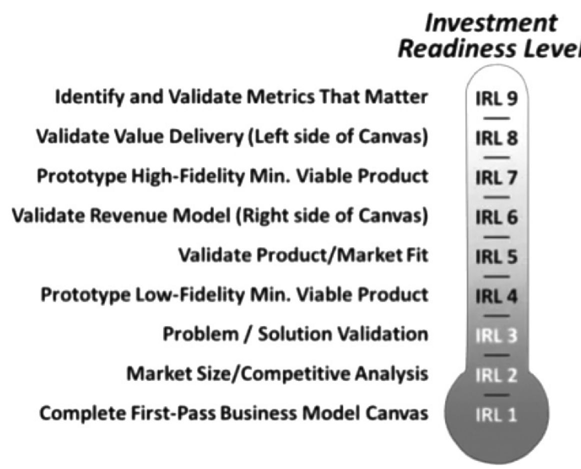

Fig. 2. Steve Blank's Investment Readiness Level [10]

Humbird (2018), a member of Lee Enterprises Consulting Inc., provides a framework for assessing technology readiness level or TRL. The technology readiness level can be rated between 1 and 9, with descriptions ranging from basic research with an elevator pitch to a full commercial deployment. Levels 1 to 3 generally require fundamental research and development, 4 to 6 involve scaling up, and 7 to 9 describe a technology being demonstrated and commercially deployed. He also describes the types of funding typically required for the different stages. Levels 1 and 2 typically require government or academic grants, 3 to 4 make use of seed rounds for funding, 5 to 7 use A to C series funding rounds and levels 8 and 9 typically need large bank loans for purchasing equipment and performing construction [11].

III. Methodology

The researchers identified key areas where existing research is concentrated, using this information to propose potential solutions. The chart below employs the five Ws to categorize and highlight these important areas.

TABLE I
The Five Ws of the Study.

Who	What	Where	When	Why
Aquacultural Producers	Precision Aquaculture Systems	The philippines	present until near future (5-10 years)	To guide future research and policy-making

The researchers provided key challenges in relation to the Five W's. Its respective solutions are also shown in the tables below.

TABLE 2
The Challenges

Challenges
Public Awareness and Interest on the Exsitence of Aquaculture
Increasing New Research and Project Related to Aquaculture
Widening of Partnerships and Collaborations for Commercialied Innovation

TABLE 3
The Solutions

Solutions
1. Industries Promoting Aquaculture through Advertisements
2. Increasing New Research and Project Related to Aquaculture
3. Widening of Partnerships and Collaborations for Commercialized Innovation.

Table 4 shows the cross-evaluation of the solutions, displaying how it affects not just its respective challenge, but also the others, with 4 being the highest and 1 being the lowest.

TABLE 4
Scoreboard

#	Challenge 1	Challenge 2	Challenge 3	Sum of Scores
1	4	4	2	10
2	2	4	6	9
3	4	4	4	12

It is seen above that solution 1 affects challenge 1 the most as promotion through advertisement would mean a higher chance of public awareness on aquaculture. As public awareness increases, corporations are likely to show more interest in researching and developing aquaculture systems, as evidenced by the effect of solution 1 on challenge 2. However, it remains uncertain whether solution 1 has an impact on challenge 3.

On the next part, it is seen that solution 2 is not transitive with challenge 1 the same way solution 1 was in synergy with challenge 2. This is mainly because it is due to demand that research and development occurs not necessarily the other way around. But solution 2 can catch the attention of the many enterprises, especially if the research is successful.

Lastly, solution 3 connects the most with all the challenges as international support will garner the attention of both public and private enterprises and this would also mean public attention for aquaculture products.

IV. Results and Discussion

The technology roadmap as seen in appendix A shows that aquaculture is growing rapidly with a growth rate of nearly 5% CAGR globally. The Philippine government has a stated goal of achieving greater food self-sufficiency, and the Department of Science and Technology is currently supporting initiatives to create aquaponic systems. This combination creates an environment conducive to the rapid growth of aquaponics in the Philippines. As a result, there is significant potential to enhance economic value and food security through advancements in precision aquaculture locally.

Appendix B's assessment of the TRL and IRL of precision aquaponics indicates that many related technologies are primed for investment. Moreover, it underscores that the foundational technologies and concepts behind precision aquaculture are fully mature and have been successfully deployed commercially. This demonstrates that investing capital and resources in rolling out and supporting precision aquaculture in the Philippines is an attractive option. It's a proven system and technology with relatively low risk, and its maturity level should allow for relatively quick returns. Its high level of technology readiness suggests that creating and incentivizing mechanisms for large-scale funding, like through banks, should be a priority for policymakers. Despite the fundamentals of the technology being proven however, the technology roadmap shows that the technologies shaping the future of precision aquaculture, like computer vision, robotics, and IoT are still rapidly evolving and continued governmental research support and knowledge dissemination may be crucial for staying globally competitive and maximising the benefits of this technology.

V. CONCLUSION

To summarise, the study was able to investigate precision aquaculture innovation ecosystem industry and use the obtained information to spot challenges and propose solutions. The evaluation resulted in solution 3 having the most impact with all the challenges with a perfect summed score of 12, while solution 2 having the lowest impact on the challenges with a score of 9.T These findings point out that partnerships with national and international governments and enterprises encourage more innovation in the industry of precision aquaculture. The researchers conclude that globally, precision aquaculture is expanding quickly, with a compound annual growth rate of around 5%. This, along with the government of the Philippines' declared intention to increase food self-sufficiency, presents a setting that may be conducive to the rapid expansion of aquaponics in the country. Although the technology's principles have been demonstrated, the technology roadmap demonstrates that IoT, robotics, and computer vision are still in the midst of a rapid evolution. Reviews of this nature can help identify challenges and potential solutions within developed ecosystems, pinpointing areas where innovation powerhouses could make significant contributions to industry advancement.

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APPENDIX

APPENDIX A

Technology Roadmap

Precision Aquaculture Philippines

	Trends	Timeline	Impact (+ / –)	Action Plan
	List current trends & future trends you are aware, of that might impact your project.	When is it likely to happen/ have an impact? (Short? Medium? Long term? Within 1, 3, or 5 years?)	What is the impact on you (or on your industry)? (If not sure of details, indicate if positive, or negative.	Develop an action plan: What do you need to do to prepare? Or, if unsure, about the trends... list how can you find out more
New Regulation & Legislation Changes	– BFAR Fisheries Resilience Projects – DOST AKBAY program aquaponics support – Stated government goal to aim for food self-sufficiency – Increased government budget allocation for agriculture and aquaculture	– In the short term more research funding may be available for food security related research – In the medium and long term more aquaponics projects may be funded and supported by the government, leading to the creation of more aquaponics and aquaculture systems	+ Government funds may be more available for the research development phase of our technology + The creation of more aquaponics and aquaculture producers will lead to a larger potential market precision aquaponics + Government funded aquaponics and aquaculture systems are a potential candidate for early adopters of the product	– Approach relevant government agencies like BFAR and DOST early for potential research support and to gauge interest in using the product in public projects – Research areas where aquaponics and aquaculture systems are being built privately and publicly, and the types of systems being built
Technology Trends and Advances	– IoT connected devices – Use of computer vision – Use of data interpretation tools – Robotics – Some decision making is automated	– Within the next 5-10 years research in precision aquaculture is likely to expand and increase in sophistication – Rapid advances in computer vision, machine learning, robotics and farm automation are expected	+ Various supporting technologies for precision aquaculture will contribute + Greater potential for increased efficiency and yields through the latest precision aquaculture technologies	– Increase efforts to disseminate the latest precision aquaculture advances and guide researchers through dedicated seminars and conferences.
Marker & Social Trends	– Expected 9.6% CAGR for aquaponics market – Increase demand for organic food products – Increased awareness and demand for sustainably grown foods as an element of climate action	– 2017-2027 – Present and foreseeable future – Present and foreseeable future	+ Overall increased demand	– Highlight strong expected marker growth in pitches – Highlight sustainability, increased accountability and greater resource use efficiency provided aquaponics

APPENDIX B

Investment Readiness Level and Technology Readiness Level

	YOUR PRODUCT/SERVICE								
IRL 9									
IRL 8									
IRL 7									
IRL 6									
IRL 5									
IRL 4									
IRL 3									
IRL 2									
IRL 1									
IRL/TRL 0	TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9

LEGEND	
	COMPLTE
	SOME COMPONENTS ARE MISSING