

Strategic Development and Sustainability of Swamp Buffalo

A Systematic Review

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Abstract

Swamp buffalo (*Bubalus bubalis*) assume a pivotal function in the agricultural and economic frameworks of Southeast Asia, acting as a vital source of labor and high-protein sustenance. Nevertheless, the sustainability of swamp buffalo husbandry encounters various challenges, including alterations in land use, shortages of labor, and the impacts of climate change. This systematic literature review, conducted in accordance with PRISMA guidelines, investigates strategic development and sustainability within swamp buffalo production through a comprehensive analysis of two decades of research (2003–2023) derived from peer-reviewed academic journals. The principal findings underscore prevailing trends in production, identifying both challenges and opportunities. Innovations focused on increasing efficiency, genetic conservation efforts and policy support are needed because the conservation of indigenous breeds and their characteristics (e.g. local water buffalo breeds that are well adapted to flooded environments) help keep buffalo populations highly genetically diverse. When faced with epidemics, a “gene pool” is needed to help improve breeds to survive in critical situations. The results indicate the potential for increased productivity through the implementation of improved herd management techniques, the utilization of innovative feed resources, and strategies aimed at mitigating methane emissions. Furthermore, the production of value-added products, such as cheese and yogurt, presents novel market opportunities. International cooperation, particularly involving stakeholders from Thailand, Australia and the Philippines on academic issues, is essential to promote sustainable practices. The study culminates in recommendations aimed at enhancing policy frameworks, adapting to climate change, and building farmer capacity to ensure the long-term sustainability and competitive viability of swamp buffalo farming.

Keywords: Swamp buffalo, Strategic development, Sustainable, Systematic review

Introduction

Water buffalo (*Bubalus bubalis*) is an important economic animal of life. It helps produce milk and meat which are high-protein food. It is used in agricultural labor, helping to produce organic fertilizers which helps promote economic and social development. Buffalo are divided into 3 types: 1. Asian water buffalo (Asiatic Water Buffalo-*Bubalus bubalis*) 2. African buffalo (Africa buffalo-*Syncerus Caffer*) 3. Dwarf buffalo (Anoas-Anoa) which Asian water buffalo (Asiatic Water Buffalo-*Bubalus bubalis*) can be divided into 2 types: 1. Swamp buffalo (River or Riverine buffalo) called "Indian buffalo" because this type of buffalo is raised a lot in India and Pakistan. Its scientific name is *Bubalus bubalis*. It has a chromosome number of $2n=50$. It is a dairy buffalo because it has large udders. And produce about 5 liters of milk/day. It is popularly raised for milk consumption (Datta, 2023). 2. Swamp buffalo (Swamp buffalo) has a scientific name of *Bubalus bubalis*, chromosome number $2n=48$ (Si et al., 2024). Swamp buffalo are widely raised in southern China, Southeast Asian countries (Thailand, Vietnam, Cambodia and Indonesia). They are raised mainly for labor and meat consumption.

In the past decades, swamp buffalo farming has faced many challenges that affect the sustainability of production. Rapid economic development and social changes have affected the traditional swamp buffalo production system. The change in land use from agricultural areas to industrial and residential areas, the shortage of agricultural labor, and the change in agricultural patterns that rely more on mechanization have all resulted in the continuous decline of the swamp buffalo population. In addition, climate change has affected the ecosystem suitable for buffalo farming, including natural food sources and animal husbandry areas. At the same time, the demand for swamp buffalo products, especially high-quality buffalo meat, has tended to increase in both domestic and export markets because consumers value nutritious food produced in environmentally friendly farming systems. Strategic development and sustainability of swamp buffalo production are therefore issues of interest to researchers, policymakers and stakeholders in the production chain. This systematic literature review aimed to analyze and synthesize knowledge on strategic development and sustainability of swamp buffalo production, covering key issues: (1) the situation and trends of swamp buffalo production, (2) challenges and opportunities for sustainable development of swamp buffalo production, (3) innovations and technologies for improving production efficiency, (4) guidelines for conservation and genetic development of swamp buffalo, and (5) policies and supporting measures necessary for sustainable development.

Methodology

This study used a systematic literature review (Systematic Review) according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to collect, analyze, and synthesize knowledge on strategic development and sustainability of swamp buffalo production. The research procedures are as follows:

1. Research question determination: Strategic Development and Sustainability of Swamp Buffalo

2. Research selection criteria determination

- 2.1 Inclusion criteria

- 2.1.1 Research articles published in international and national academic journals that have been evaluated by qualified persons (Peer-reviewed journals)

- 2.1.2 Articles published between 2003-2023

- 2.1.3 Articles related to the production, development and sustainability of swamp buffalo production

- 2.1.4 Articles published in English

- 2.2 Exclusion criteria

- 2.2.1 Articles that have not been evaluated by qualified persons

- 2.2.2 Articles that are not directly related to swamp buffalo production

- 2.2.3 Articles that are review articles, letters to the editor or opinion articles

3. Data search and collection

- 3.1 Databases used for searching International database: Scopus (Because it has a clear citation metrics function, it can view the number of citations, h-index and is a large academic literature database that collects tens of thousands of articles from international journals).

- 3.2 Keywords used for searching English: "swamp buffalo", "strategic development", "Sustainable"

4. Screening and assessment of research quality

The following information will be extracted from each article: Basic information: title, author, year of publication, journal name, and country of study.

Research Methodology: research design, sample size, data collection methods, and analytical techniques.

Research Findings: key findings related to strategic development and sustainability of swamp buffalo production.

Recommendations: author's recommendations or conclusions for policy, practice, or future research.

4.1 Preliminary screening

4.2 Screening from the title and abstract by 2 researchers independently

4.3 In case of disagreement Consult a third expert

4.4 Research quality assessment

4.5 RStudio program with Biblioshiny application

4.6 Data extraction and analysis

4.7 Use the developed standard data recording form

4.8 Record basic information of the article, study methods, study results, and recommendations

4.9 Data analysis

4.10 Content analysis

4.11 Cluster and synthesize data according to the issues specified in the objectives

5. Research result presentation

5.1 Present the results of article screening according to the PRISMA Flow Diagram

5.2 Present the results of data synthesis in the form of a narrative and summary table

5.3 Make policy and practice recommendations

6. Research quality control

6.1 Check the accuracy of the data by at least 2 researchers

6.2 Assess publication bias using Funnel Plot for quantitative data

6.3 Report the research results according to the PRISMA Checklist

Results

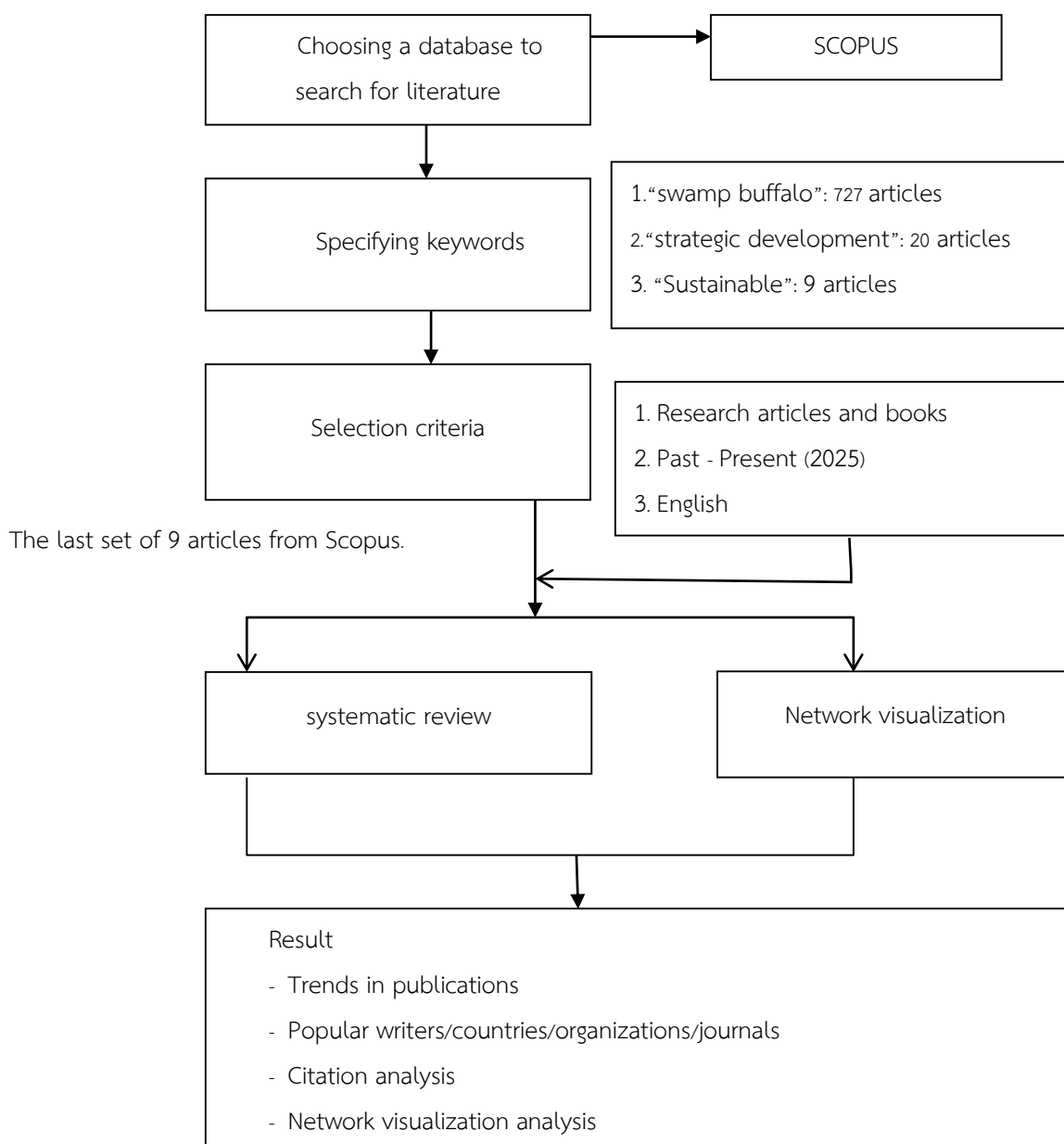


Figure 1 Structure of article selection methods to use it to systematically review the literature (Source: Researcher, 2025)

This study started by selecting the Scopus database as a source for literature search, using 3 groups of keywords: "swamp buffalo", which found 727 articles, "strategic development", found 20 articles, and "Sustainable", found 9 articles. (Adriani et al., 2024) (Ecija, N., 2010) (Foiklang et al., 2011) (Granum, 2007) (Joomjantha & Wanapat, 2008) (Nampanya et al., 2017) (Pineda et al., 2021) (Sikdar et al., 2021) (Wanapat et al., 2010) Then, the selection criteria were set to be research articles and books published from the past to the present (2025) and in English. The final 9 articles from Scopus were used to conduct a systematic literature review

and network analysis to obtain results in terms of publication trends, frequently published authors/ countries/ organizations/ journals, citation analysis, and network display analysis. Research results

Table 1 Selected Articles and Books on Strategic Development and Sustainability of Swamp Buffalo

Publication Year	Author(s)	Times Cited	Source	Title
2007	GRANUM G;WANAPAT M;PAKDEE P;WACHIRAPAKORN C;TOBURAN W	20	Asian-australasian journal of animal sciences	A comparative study on the effect of cassava hay supplementation in swamp buffaloes (<i>bubalus bubalis</i>) and cattle (<i>bos indicus</i>)
2008	JOOMJANTHA S;WANAPAT M	1	Livestock research for rural development	Effect of supplementation with tropical protein-rich feed resources on rumen ecology, microbial protein synthesis and digestibility in swamp buffaloes
2010	FOIKLANG S;WANAPAT M;TOBURAN W	20	Journal of animal and veterinary advances	Effect of various plant protein sources in high-quality feed block on dry matter intake, digestibility and rumen fermentation in swamp buffalo
2010	CRUZ LC	0	Revista veterinaria	Recent developments in the buffalo industry of asia
2010	WANAPAT M;KONGMUN P;CHANTHAKHOUN V;CHERDTHONG A;PILAJUN R	1	Revista veterinaria	Use of local feed resources to improve rumen fermentation and reduce methane production in buffalo production in southeast asia
2017	NAMPANYA S;KHOUNSY S;YOUNG JR;NAPASIRTH V;BUSH RD;WINDSOR PA	1	Animal production science	Smallholder large ruminant health and production in lao pdr: challenges and opportunities for improving domestic and regional beef supply
2021	PINEDA PS;FLORES EB;HERRERA JRV;LOW WY	11	Frontiers in genetics	Opportunities and challenges for improving the productivity of swamp buffaloes in southeastern asia
2021	SIKDAR S;DAS T;SAJIB EH;RAHMAN KMU;SIDDIKI AZ;UDDIN MB	2	Journal of buffalo science	Multi-omics and molecular biology perspective in buffalo genome
2024	ADRIANI D; YAZID M;RISWANI R;DAMAYANTHY D;CHOI E;YANG H	25	Land	Livelihood alternatives in restored peatland areas in south sumatra province, indonesia

Table 1 presents the empirical data pertinent to the strategic advancement and sustainability of the swamp buffalo, which is categorized into five principal components: year of publication, authorship, citation count, source of information, and the title of the study. The year of publication serves as an indicator of the research's contemporaneity and relevance, encompassing the period from 2007 to 2024. In the authorship segment, the primary researchers along with their collaborators are enumerated. The number of citations in each research reflects the impact and importance of that research. Certain scholarly inquiries, notably those conducted in 2007 and 2024, exhibit citation counts of 20 and 25, respectively, thereby underscoring the significance of the subjects and themes examined. Furthermore, the origins of these investigations encompass a diverse array of academic periodicals, including the Asian-Australasian Journal of Animal Sciences and Frontiers in Genetics, which serve to enhance the reliability and scholarly merit of the published works.

Empirical investigations have demonstrated that the cultivation of swamp buffalo represents a lucrative venture for agricultural practitioners, evidenced by an internal rate of return (IRR) of 30.28% and a benefit-cost ratio (B/C) of 4.90 (Adriani et al., 2024). Despite the fact that swamp buffalo farming serves as the principal source of revenue for populations residing in the swamp region, it currently faces several constraints. It is noteworthy that farmers seldom market buffalo in commercial venues; rather, they typically resort to slaughtering these animals for meat, which is subsequently utilized in religious rites, matrimonial celebrations, and various social gatherings. Buffalo milk production is still limited, at 1-3 liters/buffalo/day. Buffalo milk products found most in South Sumatra have commercial value and contribute to the economy of farmers. Nevertheless, these animals remain largely unfamiliar to the general populace beyond the boundaries of South Sumatra, and their consumption levels continue to be notably modest. Empirical studies indicate that the cultivation of swamp buffalo can be enhanced to yield greater profitability and sustainability through the optimization of herd management practices, augmentation of buffalo milk output, and the advancement of marketing strategies for buffalo milk derivatives (Pineda et al., 2021). Furthermore, the transformation of buffalo milk into alternative commodities such as butter, cheese, and yogurt have the potential to enhance value and provide increased financial returns for agricultural producers.

A comparative study of the prominence of various occupations found that swamp buffalo farming had the highest B/C ratio compared to other occupations, indicating that

swamp buffalo farming is a very profitable occupation. However, it can be combined with other alternative occupations, such as non-burning rice farming, Agrosilvofishery, and wetland farming (pluviculture), resulting in stable income throughout the year. It also has a positive impact on the environment, reducing greenhouse gas emissions from agricultural areas or degraded forest areas and reducing the risk of forest fires (Wanapat et al., 2010). The research titles in this table clearly indicate the issues studied, such as protein supplementation in animal feed, animal nutrition development in Asia, and opportunities for developing regional livestock industries. These issues focus on the strategic and sustainable development of swamp buffalo and reducing environmental impacts. They provide important data for analyzing research trends in animal nutrition and can be used as a reference for developing relevant policies or projects at regional and international levels effectively.

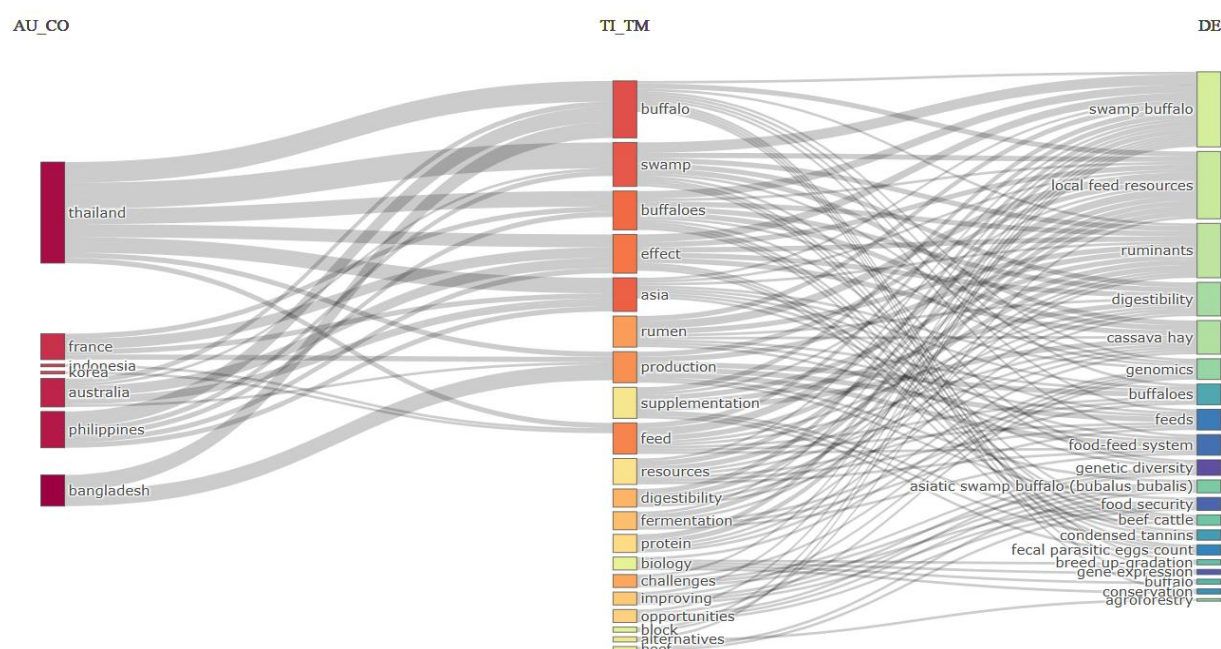


Figure 2 Sankey Diagram showing the relationships between countries, researchers, topics, and keywords in buffalo research (Source: RStudio program with Biblioshiny application)

From Figure 2, it was found that the linkage of articles with titles and keywords, Thailand had the most links with 39 links, Philippines 14 links, Bangladesh 12 links, Australia 11 links, France 10 links, Korea 1 link, Indonesia 1 link. It was found that the top 5 linked topics were buffalo, swamp, buffaloes, effect, asia, respectively. It was found that the most linked keywords were Swamp buffalo, local feed resource, ruminants, digestibility, cassava hay, respectively.

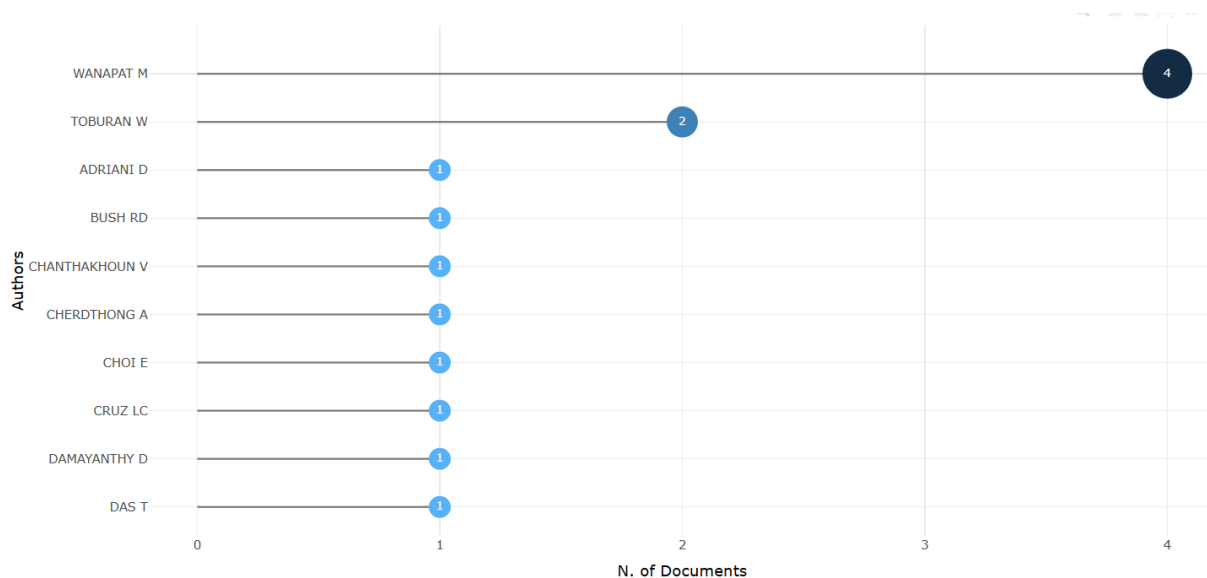


Figure 3 Most Relevant Authors (Source: RStudio program with Biblioshiny application)

From Figure 3, the work of WANAPAT M was cited the most, 4 times, followed by the work of TOBURAN W.

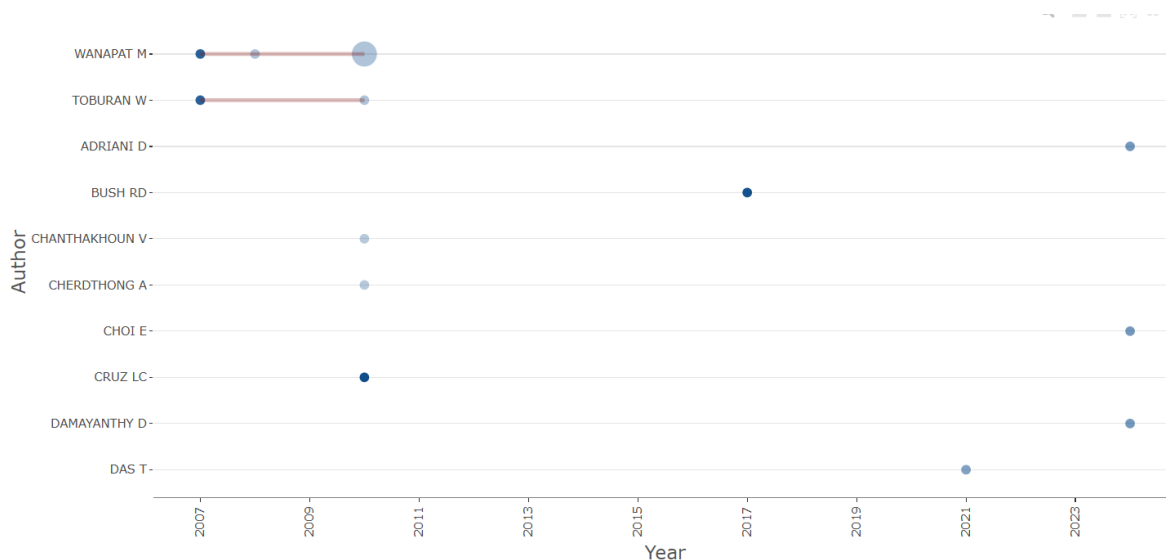


Figure 4 Authors' Production over Time

(Source: RStudio program with Biblioshiny application)

From Figure 4, the work of WANAPAT M and TOBURAN W played an important role in the early period 2007-2010, but currently it is the work of ADRIANI D, CHOI E, DAMAYANTHY D.

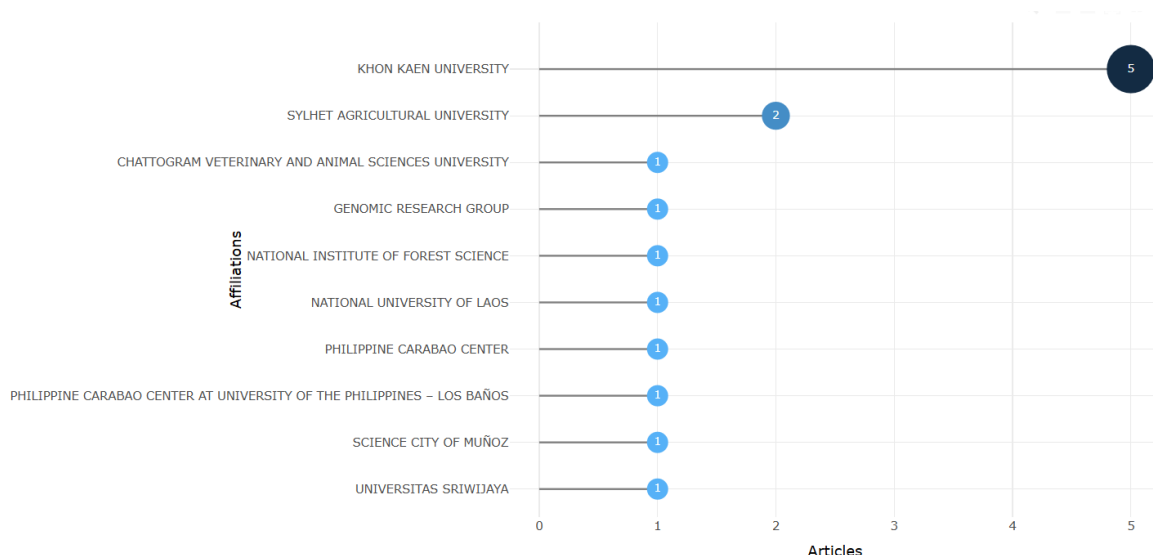


Figure 5 Most Relevant Affiliations (Source: RStudio program with Biblioshiny application)

From Figure 5 , it was found that the agencies related to the work on Strategic Development and Sustainability of Swamp Buffalo were KHON KAEN UNIVERSITY, which was most involved with 5 articles, followed by SYLHET AGRICULTURAL UNIVERSITY, which was involved with 2 articles.

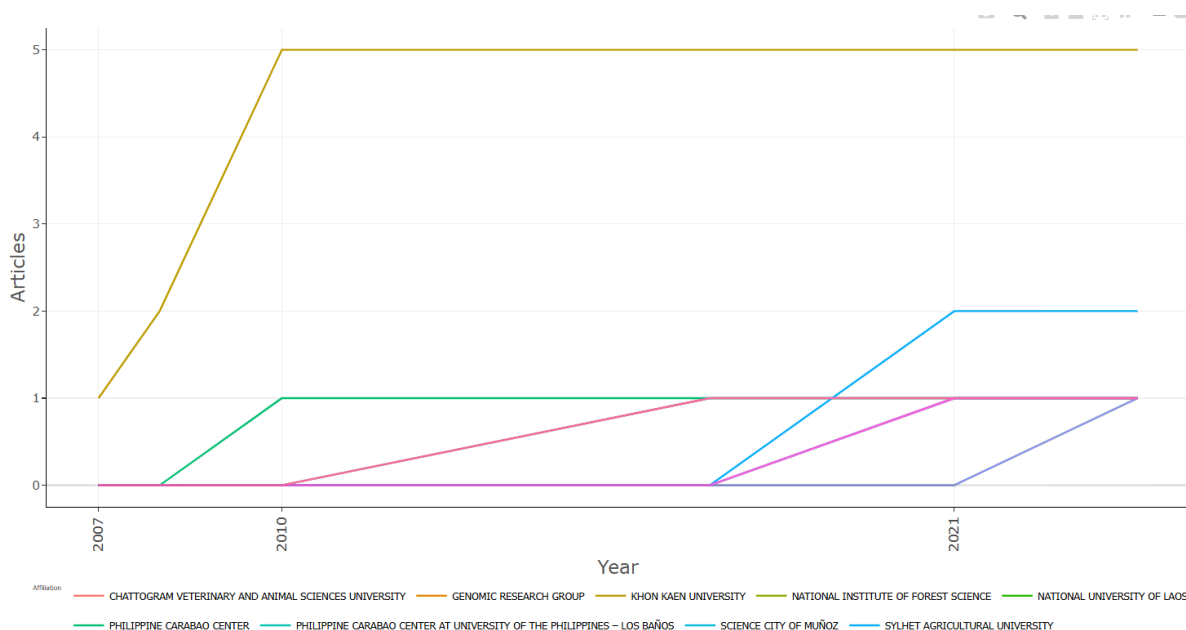


Figure 6 Affiliations' Production over Time

(Source: RStudio program with Biblioshiny application)

From Figure 6, it is evident that the organizations consistently engaged in the initiatives pertaining to Strategic Development and Sustainability of the Swamp Buffalo are

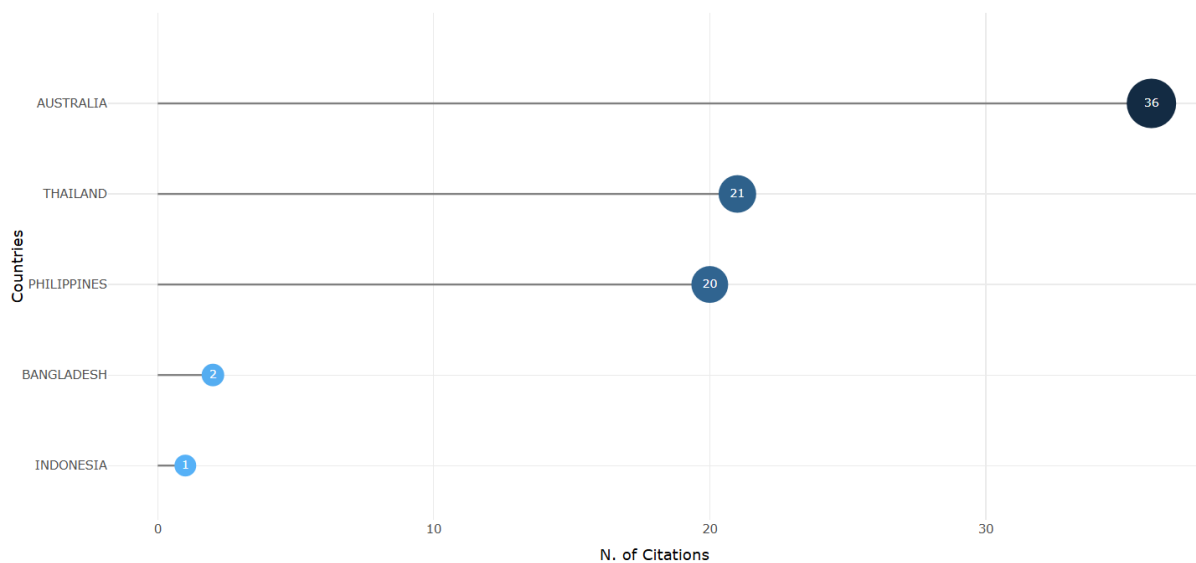


Figure 7 Most Cited Countries (Source: RStudio program with Biblioshiny application)

From Figure 7, the country whose work was referenced the most was Australia, with 36 times, followed by Thailand, with 21 times, and the Philippines, with 20 times.

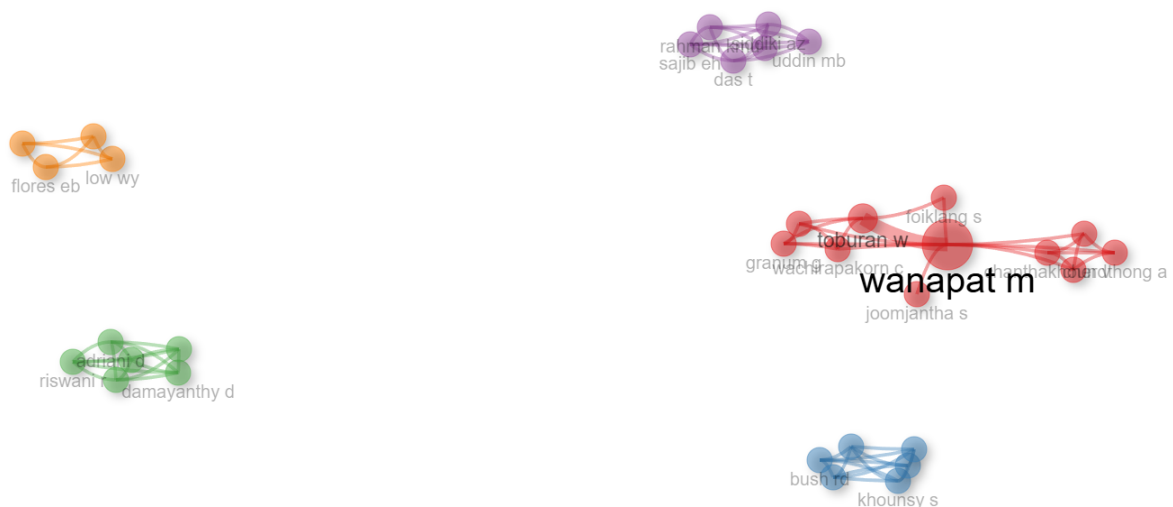


Figure 8 Collaboration Network (Source: RStudio program with Biblioshiny application)

From Figure 8, researchers involved in the work on Strategic Development and Sustainability of Swamp Buffalo work in a narrow group, with little cooperation in research.



Figure 9 Countries' Collaboration World Map
(Source: RStudio program with Biblioshiny application)

Figure 9 shows this world map showing international research collaboration, highlighting key countries such as Thailand, Australia, France, Indonesia, Philippines, and Bangladesh, using different colors to highlight each country's involvement in research networks. International connections represent collaborative relationships, such as joint research publications or international data exchanges. Lines drawn from Thailand to other countries such as Australia and France reflect Thailand's important role as a hub for international collaboration.

Discussions

Strategic development and sustainability of swamp buffalo using a systematic literature review following PRISMA guidelines, collecting data from research articles published between 2003–2023 in the Scopus database, focusing on 5 main themes: production situation and trends, challenges and opportunities, innovation and technology, genetic conservation, and policies supporting sustainable development.

Swamp buffalo are an important economic animal in Southeast Asia, playing a role in agricultural labor and a source of protein. Considering these challenges, the study advocates for innovative solutions to enhance production efficiency. By harnessing local resources, formulating premium animal feeds, and implementing strategies to mitigate methane emissions, the buffalo industry can adapt and thrive, ensuring the survival of these majestic

creatures while meeting the growing needs of conscientious consumers. Conservation of swamp buffalo genetics has also been identified as an important goal, as well as the development of marketing strategies that add value to products such as milk, cheese, and yogurt. Dairy buffaloes are popular in India due to their efficient milk production, superior milk quality, disease resistance, longer production life and higher milk yield. They contribute significantly to the country's milk production with 45.07% coming from buffalo alone. (Datta, 2023). Thailand plays a key role in this research, collaborating with other countries such as Australia and the Philippines to develop and promote swamp buffalo sustainability at regional and international levels (Lambertz et al., 2012). The paper also highlights the need for policies that support future economic and environmental changes.

Conclusion and Suggestions

Studies have shown that swamp buffalo herding is an important part of the socio-economic system in Southeast Asia, as swamp buffalo play a role in both agricultural labor and protein sources. However, the conversion of agricultural land to habitat and industry, labor shortages, and the impacts of climate change, temperature affect lactation in domestic buffalo, such as the Surti breed in India (Jeetendra et al., 2014). Heat stress affects livestock systems by altering feed availability, health, and reproduction (Paul, 2022) (Jean, 2019), leading to a continuous decline in swamp buffalo numbers, despite an increase in demand for buffalo products such as high-quality meat and milk.

Innovation and technology are highlighted as important alternatives to solve the problem, whereby utilizing local resources, developing high-quality animal feeds, and reducing methane emissions can help increase production efficiency and create long-term sustainability. In addition, conservation of swamp buffalo genetics should be promoted along with supporting product processing such as cheese, butter, and yogurt production (Sumit et al., 2022). Malaysia can process imported buffalo meat into value-added products such as hamburgers, sausages, meatballs, and nuggets. Currently, 35-40% of imported buffalo meat is processed, driven by demand from the fast-food industry (Abdul & Komate, 2013).

Recommendations from this study should emphasize policy support and systematic international cooperation. Thailand, as a research and cooperation hub, should use this potential to develop appropriate swamp buffalo production strategies for each local context, including establishing networks with regional countries such as Australia and the Philippines

to exchange knowledge and develop projects that focus on sustainability. Further research on mitigating the impacts of climate change on swamp buffalo farming should be promoted, and farmers should be supported to equip them with the knowledge and skills needed to adapt and increase their productivity to meet rapidly changing market demands and maintain long-term sustainability.

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