Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(4): 4657 – 4672 (2025)
www.ejabf.journals.ekb.eg

Land Suitability Evaluation for Pacific White Shrimp Aquaculture Development in West Halmahera, Indonesia

Tamrin Tamrin[1*], Taufiq Abdullah[2]

[1]Department of Aquaculture, Faculty of Fisheries and Marine Science, Khairun University, Ternate, North Maluku Province, Indonesia
[2]Department of Aquaculture, Faculty of Marine and Fisheries Technology, Gorontalo State University, Gorontalo, Gorontalo Province, Indonesia

[*]Corresponding Author: amboasse100676@gmail.com

ARTICLE INFO

Article History:
Received: May. 27, 2025
Accepted: July 15, 2025
Online: Aug. 10, 2025

Keywords:
Coastal area,
Land suitability,
Pacific white shrimp,
West Halmahera

ABSTRACT

Pacific white shrimp has emerged as a high-value economic commodity extensively developed in various countries including Indonesia. Several areas have been designated for its aquaculture development. West Halmahera Regency is recognized as one of the potential regions for such development. This study aimed to evaluate the land suitability for Pacific white shrimp aquaculture in the coastal regions of West Halmahera Regency, North Maluku Province, Indonesia. Observations were conducted at eight existing pond sites: Toniku (TU), Tewe (TE), Dodinga (DA), Tuada (TA), Payo (PO), Bobo (BO), Sahu (SU), and Ibu (IU). Data collection involved assessing infrastructure, water quality, and soil conditions. The collected data were analyzed for land suitability and further visualized through tabulated results and land suitability maps. The analysis revealed that the TU area has 70.06 Ha classified as moderately suitable; the TE area has 55.70 Ha classified as moderately suitable; the DA area has 27.52 Ha classified as moderately suitable; the TA area has 96.39 Ha classified as highly suitable; the PO area has 46.71 Ha classified as moderately suitable; the BO area has 39.43 Ha classified as moderately suitable; the SU area has 77.34 Ha classified as highly suitable; and the IU area has 300.40 Ha classified as highly suitable and 315.36 Ha as moderately suitable. The study concludes that based on parameters of infrastructure, water quality, and soil conditions, the Toniku, Tewe, Dodinga, Tuada, Payo, Bobo, Sahu, and Ibu areas in West Halmahera Regency, are suitable for Pacific white shrimp aquaculture development.

INTRODUCTION

Global aquaculture production continues to exhibit a significant upward trend to meet the world's food demands. In 2022, global aquaculture production reached a high record of 130.9 million tons, with an estimated farm-gate value of USD 312.8 billion **(FAO, 2024)**. Various species have been successfully cultivated, with Pacific white shrimp (*Penaeus vannamei*) being a notable example **(N'Souvi & Sun, 2025)**. This species ranked as the most produced in 2022, with a production volume of 6.8 million tons **(FAO, 2024)**.

Pacific white shrimp has emerged as a high-value economic commodity widely cultivated across several countries, including Indonesia, recognized as one of the leading producers **(Davis *et al.*, 2022; Muthu *et al.*, 2024)**. The species offers several comparative advantages, such as high survival rates, the availability of quality seed stock maintained through Specific Pathogen-Free (SPF) programs, the ability to be cultured at high stocking densities, and resistance to diseases **(Alday-Sanz *et al.*, 2020; Villarreal, 2023)**.

However, the development of Pacific white shrimp aquaculture faces substantial challenges. Site selection plays a critical role in determining aquaculture productivity. Traditional and semi-intensive aquaculture systems for the black tiger shrimp (*P. monodon*) and Pacific white shrimp have experienced declining production due to poor water suitability in aquaculture areas, as observed in Sidoarjo Regency, East Java **(Hukom *et al.*, 2020)**. Factors such as soil suitability, water salinity, land depth, and infrastructure are key to optimizing aquaculture yields **(Hadipour *et al.*, 2015)**. Without planned land management, negative environmental impacts, including water pollution and coastal ecosystem degradation, may occur, ultimately threatening the sustainability of the aquaculture sector **(Beveridge & Brummett, 2015)**. Therefore, land suitability analysis is a critical initial step in planning sustainable aquaculture development **(Assefa & Abebe, 2018)**.

The land suitability analysis process serves as a key indicator in planning optimal aquaculture land use **(Purnomo *et al.*, 2022)**. This is evident in the early development phases of a 2,399-hectare Pacific white shrimp aquaculture project in Barru Regency, as well as the development of intensive and super-intensive aquaculture systems in Takalar, Jeneponto, and Bulukumba Regencies of South Sulawesi Province **(Tantu *et al.*, 2019; Mustafa *et al.*, 2023)**. Additionally, West Halmahera Regency has been identified as a potential region for Pacific white shrimp aquaculture development. The coastal area of Jailolo District, for instance, offers 329.27 hectares of suitable land for brackish water aquaculture, particularly for Pacific white shrimp cultivation **(Tamrin *et al.*, 2024)**. Several other areas within the region remain unmapped for their land suitability. This study aimed to evaluate the land suitability for the development of the Pacific white shrimp aquaculture in West Halmahera Regency.

MATERIALS AND METHODS

1. Study area

This study was conducted across eight existing aquaculture pond sites along the coastal areas of West Halmahera Regency, North Maluku Province, Indonesia. These sites include Toniku (TU), Tewe (TE), Dodinga (DA), Tuada (TA), Payo (PO), Bobo (BO), Sahu (SU), and Ibu (IU) regions. The local government has designated intertidal zones for fisheries development, and portions of these areas have been converted into aquaculture ponds.

2. Data collection

Data collection involved gathering information on infrastructure parameters, water quality parameters, and soil parameters **(Hadipour *et al.*, 2015; Tamrin *et al.*, 2024)**. Infrastructure data included the distance to markets, main roads, and hatcheries, which were measured through direct *in situ* observations. Water quality parameters monitored included water temperature, salinity, dissolved oxygen (DO), water pH, total ammonia nitrogen (NH_3), nitrite (NO_2^-), hydrogen sulfide (H_2S), mercury (Hg), lead (Pb), and cadmium (Cd). Data for temperature (using a thermometer), salinity (using a refractometer), dissolved oxygen (using a DO meter), and water pH (using a pH meter) were collected *in situ*. In contrast, measurements for NH_3, NO_2^-, H_2S, Hg, Pb, and Cd were conducted *ex situ* in a laboratory using a spectrophotometer. Soil parameters, including soil pH, were measured *in situ* using a pH meter.

3. Data analysis

The collected data were analyzed using a water suitability assessment to determine the appropriateness of each site for aquaculture based on infrastructure, water quality, and soil parameters. The land suitability criteria were categorized into four classes: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and non-suitable (N). These classes were assigned scores of 4 for S1, 3 for S2, 2 for S3, and 1 for N. Each parameter was weighted based on its significance (Table 1). The scoring and weighting values were then used to calculate the total score range for each suitability class, where S1 ranged from 326–400, S2 from 251–325, S3 from 176–250, and N from 100–175. The suitability analysis results for the TU, TE, DN, TA, PO, BO, SU, and IU areas were tabulated to develop suitability maps following the procedures of **(Hossain & Das, 2010)**.

Tabel 1. The classification criteria for the land suitability evaluation for Pacific white shrimp aquaculture development in West Halmahera, Indonesia

Parameters	Range	Rating Score (A)	Weight (B)	Score (AxB)
Infrastructure Parameter				
Distance to markets (km)	<3	4	5	20
	3 – 7	3		15
	7 – 12	2		10
	>12	1		5
Distance to main roads (km)	<2	4	5	20
	2 – 3	3		15
	3 – 5	2		10
	>5	1		5
Distance to hatcheries (km)	<3	4	5	20
	3 – 7	3		15
	7 – 12	2		10
	>12	1		5

Table 1 (continued)

Parameter	Range	Rating Score (A)	Weight (B)	Score (AxB)
Water Quality Parameter				
Temperature (℃)	28 – 32	4	15	80
	33 – 36	3		60
	24 – 27	2		40
	<24 and >37	1		20
Salinity (ppt)	15 – 25	4	15	60
	26 – 35	3		45
	5 – 14	2		30
	<5 and >35	1		15
Dissolved oxygen (mg/L)	4.0 – 7.5	4	15	60
	3.0 – 3.9	3		45
	> 7.5	2		30
	< 30	1		15
Water pH	7.5 – 8.5	4	5	20
	6.0 – 7.0	3		15
	8.6 – 9.0	2		10
	<6.0 and >9.0	1		5
Total ammonia nitrogen (mg/L)	<0.1	4	5	20
	0.2 – 0.5	3		15
	0.6 – 1.0	2		10
	>1.0	1		5
Nitrite (mg/L)	0 - 0.05	4	5	20
	0.06 - 0.09	3		15
	1 - 1.4	2		10
	>1.5	1		5
Hydrogen sulfide (mg/L)	<0.01	4	5	20
	0.02 – 0.20	3		15
	0.21 – 0.40	2		10
	>0.41	1		5
Mercury (mg/L)	0 - 0.019	4	5	20
	0.2 – 0.3	3		15
	0.4 - 0.13	2		10
	>1	1		5
Lead (mg/L)	<0.1	4	5	20
	0.1- 0.2	3		15
	0.2 – 0.4	2		10
	>0.5	1		5

Table 1 (continued)

Parameter	Range	Rating Score (A)	Weight (B)	Score (AxB)
Cadmium (mg/L)	0 - 0.016	4	5	20
	0.2 – 0.3	3		15
	0.4 - 0.13	2		10
	>1	1		5
Soil Quality Parameter				
Soil pH	6.5 – 8.5	4	5	20
	5.5–6.4 and 8.6–9.0	3		15
	4–5.4 and 9.1–10	2		10
	<4 and >10	1		5

Source: **Tamrin *et al.* (2024)**.

RESULTS

1. Infrastructure, water quality, and soil parameters

Infrastructure, water quality, and soil condition parameters significantly influence aquaculture activities. Observations of these parameters along the coastal areas of West Halmahera Regency are summarized in Table (2). Current infrastructure factors, such as road access, market proximity, and hatchery availability, reveal several limitations. All observed sites are located more than 5km from the nearest road, exceeding the optimal distance of <2 km. Distances to local markets are greater than 12km, with the central market located approximately 31.56km away in Ternate City. Hatchery units are also situated over 12km from the sites, with fry typically sourced from Barru Regency, South Sulawesi.

Water quality measurements show that temperatures range from 29.83 to 30.33°C, within the optimal range of 28– 33°C. Salinity levels vary between 14.33 and 28.00ppt, falling within the ideal range of 5– 40ppt. Dissolved oxygen concentrations range from 4.93 to 6.40mg/ L, aligning with the optimal 5– 7mg/ L. pH values vary between 7.22 and 7.96, which is suitable for aquaculture. Total ammonia nitrogen concentrations are generally within the acceptable limit (< 0.1mg/ L), except at the Tewe site (1.112mg/ L), which remains within the tolerable limit (<1.25 mg/L). Nitrite levels range from 0.018 to 0.026mg/ L, meeting the < 0.5mg/ L standard. Hydrogen sulfide concentrations are below 0.001mg/ L, well within the acceptable limit of <0.01 mg/L. Heavy metals—including mercury (0.0001– 0.0005mg/ L), lead (0.0058– 0.0108mg/ L), and cadmium (0.0013– 0.0024mg/ L)—are all within safe concentrations.

Soil pH varies considerably between locations, ranging from 4.08 to 7.50. Most sites (Toniku, Tewe, Dodinga, Payo, Bobo, and Ibu) are acidic and do not meet the optimal range of 6.5–7.5, although all remain above the lethal threshold of 3.7 for shrimp.

Table 2. Infrastructure, water quality, and soil quality conditions

Parameter	Area							
	TU	TE	DA	TA	PO	BO	SU	IU
Distance to markets (km)	>12	>12	>12	>12	>12	>12	>12	>12
Distance to main roads (km)	>5	>5	>5	>5	>5	>5	>5	>5
Distance to hatcheries (km)	>12	>12	>12	>12	>12	>12	>12	>12
Temperature (°C)	30.00	30.00	29.83	30.00	30.00	30.33	30.00	30.00
Salinity (ppt)	27.00	26.83	28.00	26.67	19.83	20.00	23.17	14.33
Dissolved oxygen (mg/L)	5.51	5.75	5.98	5.57	5.65	6.40	5.56	4.93
Water pH	7.96	7.72	7.22	7.50	7.24	7.41	7.62	7.37
Total ammonia nitrogen (mg/L)	0.308	1.112	0.370	0.345	0.318	0.660	0.319	0.378
Nitrite (mg/L)	0.019	0.019	0.018	0.019	0.018	0.026	0.018	0.019
Hydrogen sulfide (mg/L)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury (mg/L)	0.0002	0.0001	0.0005	0.0002	0.0001	0.0002	0.0002	0.0002
Lead (mg/L)	0.0024	0.0017	0.0013	0.0013	0.0020	0.0012	0.0014	0.0018
Cadmium (mg/L)	0.0078	0.0108	0.0096	0.0096	0.0058	0.0089	0.0102	0.0078
Soil pH	4.42	4.33	4.50	6.00	4.08	4.50	7.50	4.50

Note: TU (Toniku Area), TE (Tewe Area), DA (Dodinga Area), TA (Tuada Area), PO (Payo Area), BO (Bobo Area), SU (Sahu Area), and IU (Ibu Area).

2. Land suitability

The site assessment results indicate that the Toniku (TU) area, covering 70.06 ha, is categorized as moderately suitable (S2) (Fig. 1). The Tewe (TE) area, with 55.70 ha, is also classified as moderately suitable (S2) (Fig. 2). The Dodinga (DA) area, covering 27.52 ha, falls into the moderately suitable (S2) category (Fig. 3). The Tuada (TA) area, measuring 96.39 ha, is classified as highly suitable (S1) (Fig. 4). The Payo (PO) area, with 46.71 ha, is categorized as moderately suitable (S2) (Fig. 5). The Bobo (BO) area, covering 39.43 ha, is also moderately suitable (S2) (Fig. 6). The Sahu (SU) area, with 77.34 ha, is considered highly suitable (S1) (Fig. 7). The Ibu (IU) area includes 300.40 ha of highly suitable (S1) land and 315.36 ha of moderately suitable (S2) land (Fig. 8).

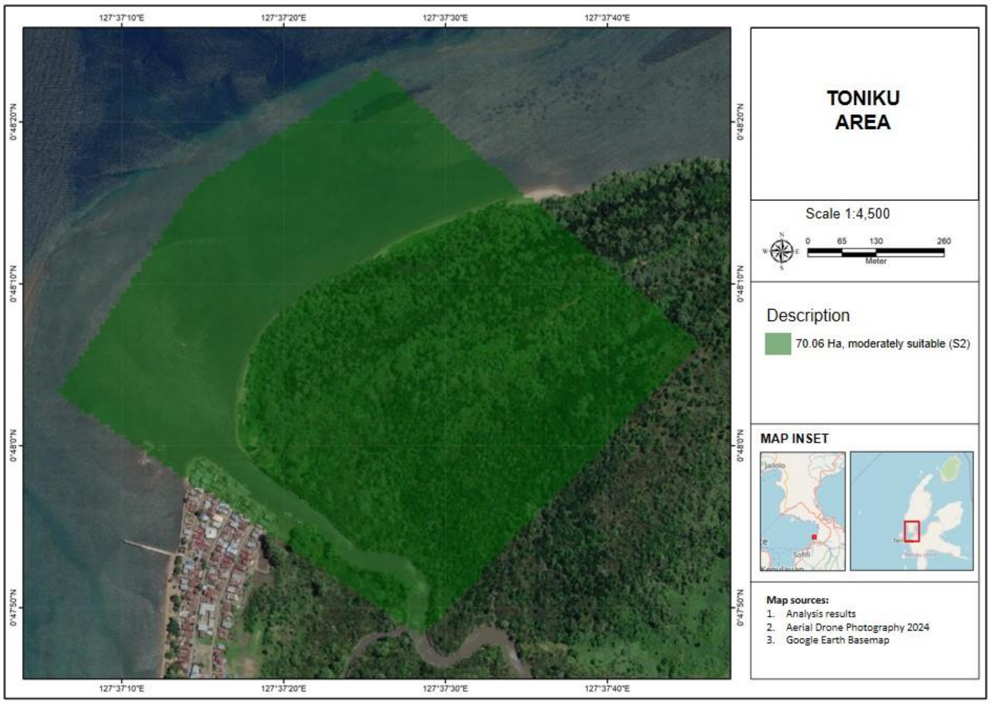

Fig. 1. Land suitability map for Pacific white shrimp aquaculture development in Toniku Area

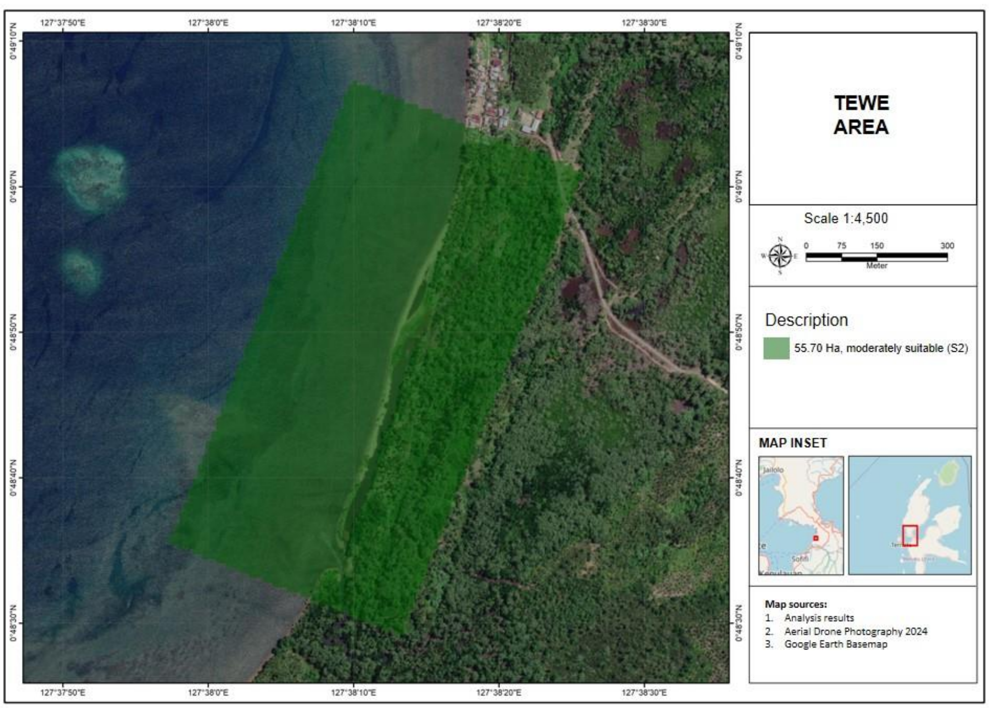

Fig. 2. Land suitability map for Pacific white shrimp aquaculture development in Tewe Area

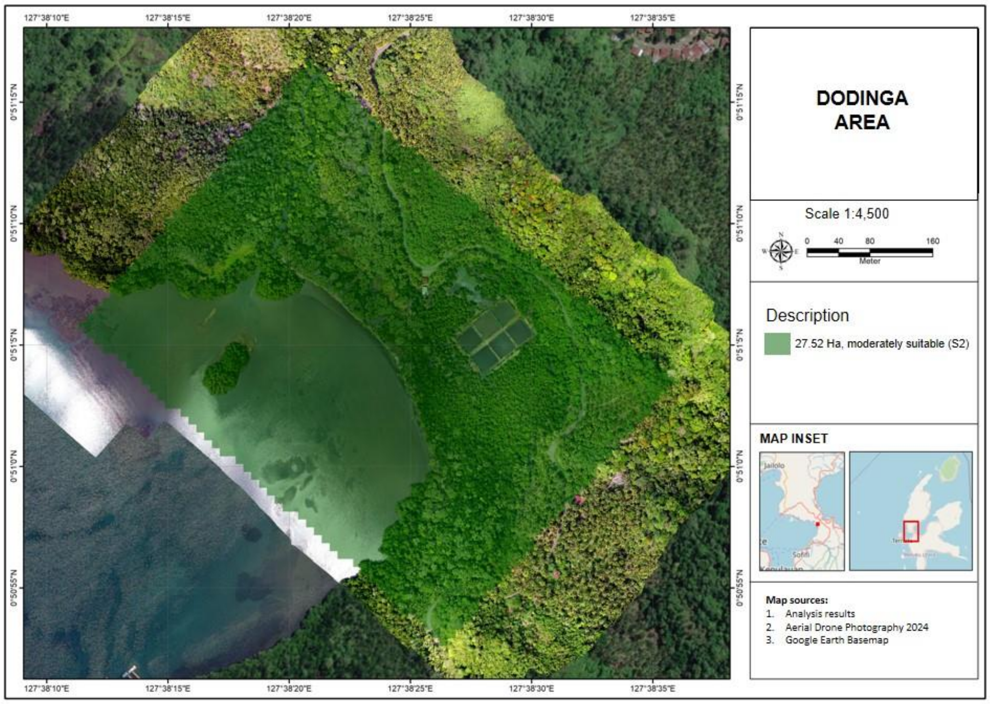

Fig. 3. Land suitability map for Pacific white shrimp aquaculture development in Dodinga Area

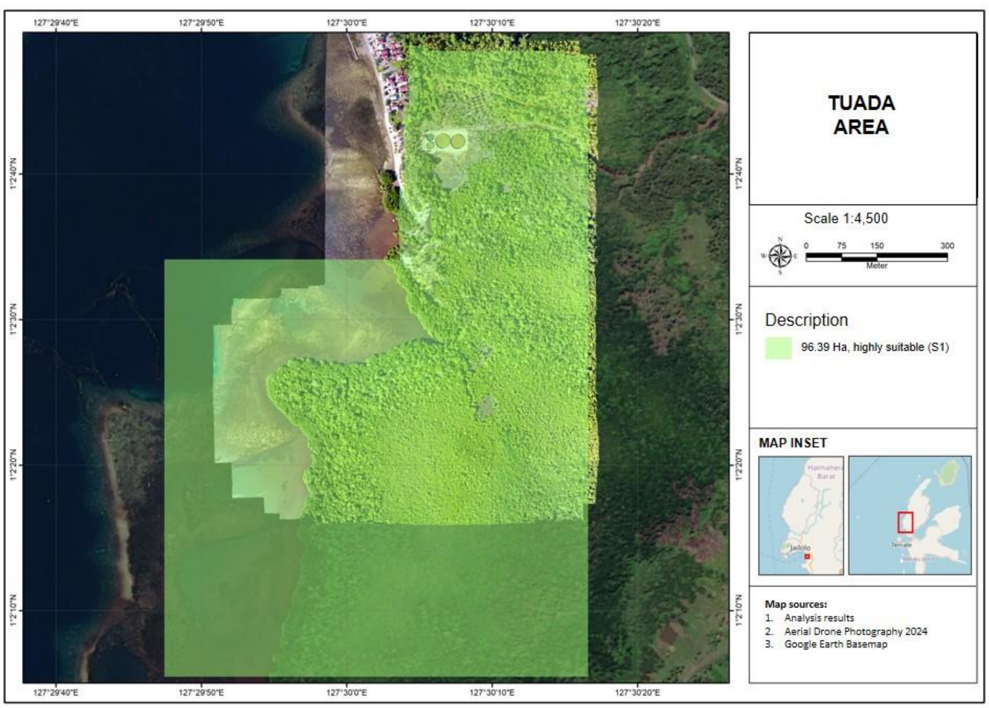

Fig. 4. Land suitability map for Pacific white shrimp aquaculture development in Tuada Area

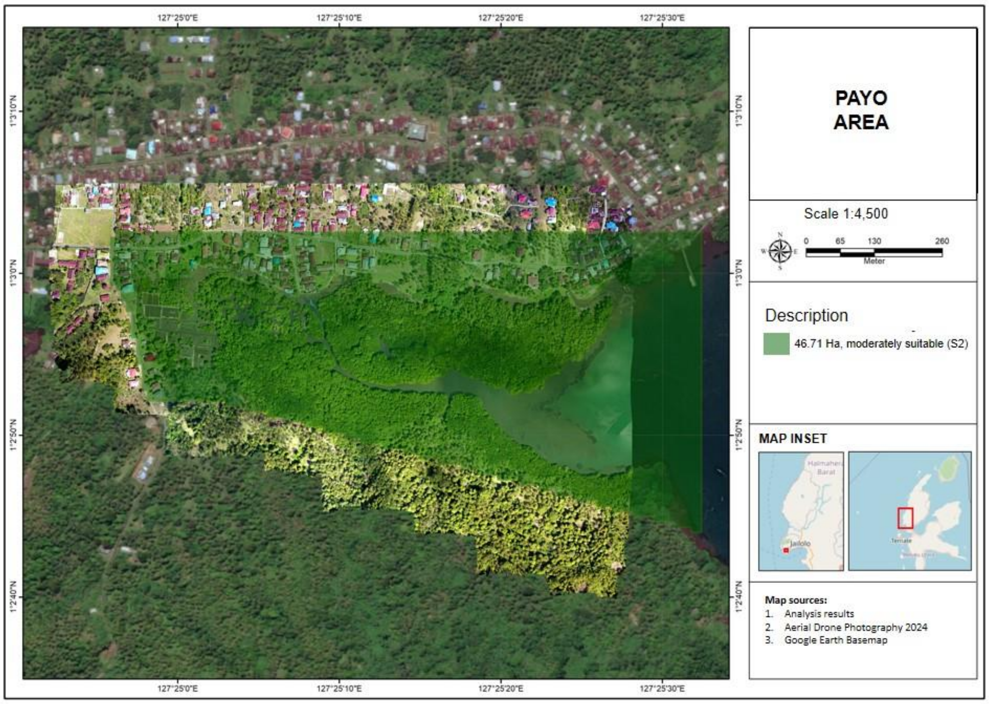

Fig. 5. Land suitability map for Pacific white shrimp aquaculture development in Payo Area

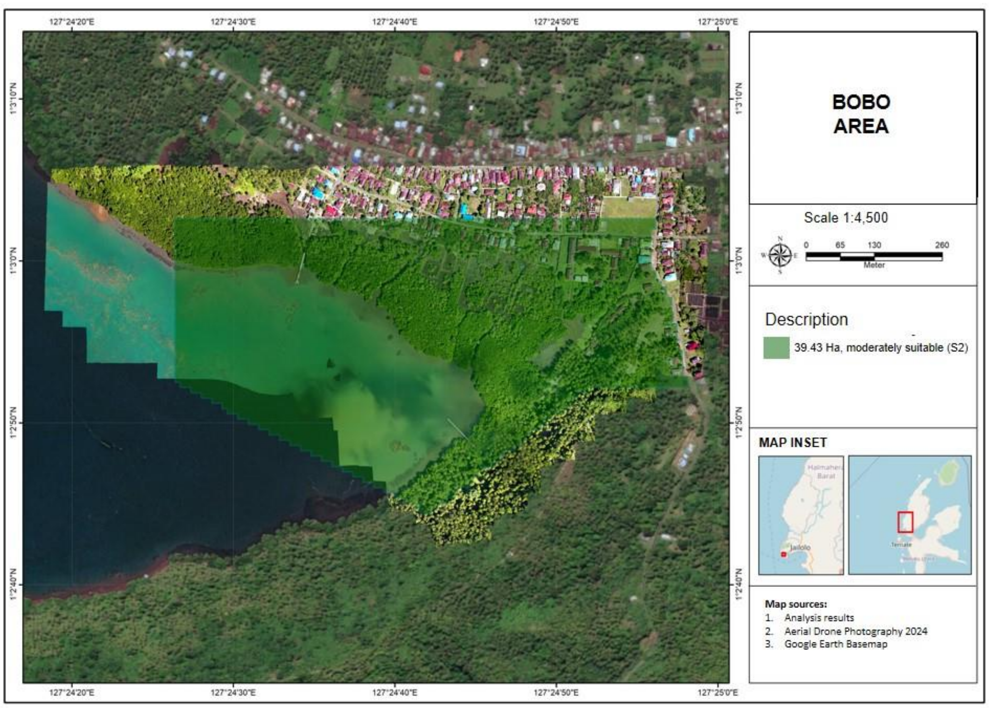

Fig. 6. Land suitability map for Pacific white shrimp aquaculture development in Bobo Area

Fig. 7. Land suitability map for Pacific white shrimp aquaculture development in Sahu Area

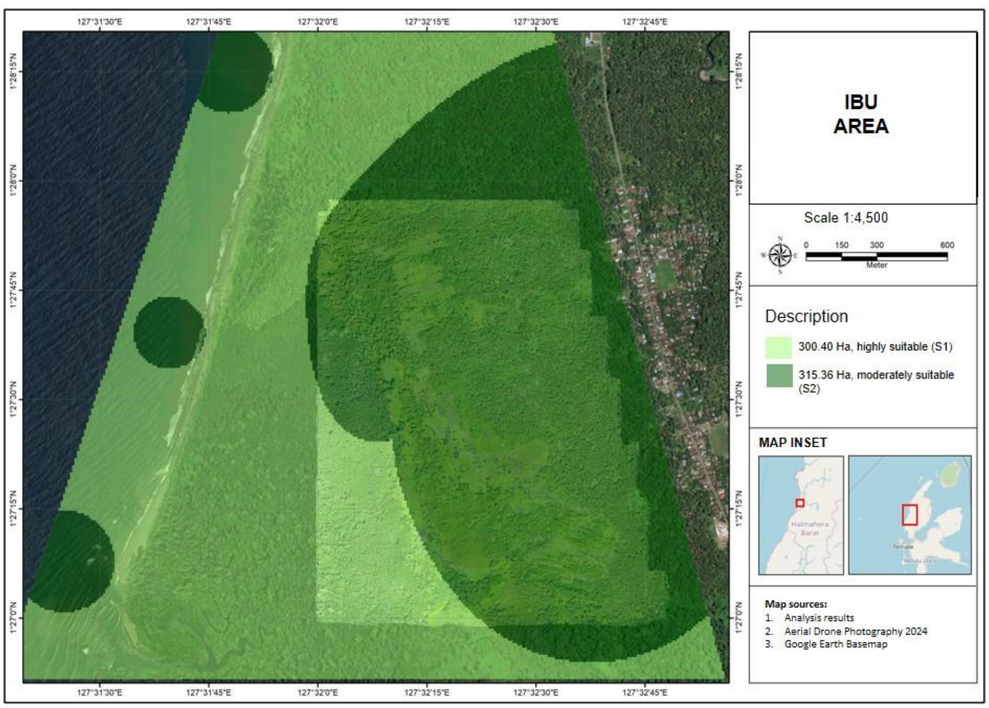

Fig. 8. Land suitability map for Pacific white shrimp aquaculture development in Ibu Area

DISCUSSION

Infrastructure, water quality, and soil condition parameters significantly influence aquaculture activities **(Hadipour *et al.*, 2015; Tamrin *et al.*, 2024)**. Observations of these parameters along the coastal areas of West Halmahera Regency are presented in Table (2). Key infrastructure factors—such as road access for ease of transportation, post-harvest marketing facilities, and the proximity of hatchery units—play a critical role in operational efficiency. Development sites should ideally be located near the main road network. However, observations indicate that the distance to the nearest road exceeds 5km in all areas (Table 2), exceeding the optimal condition of less than 2km **(Hadipour *et al.*, 2014)**.

Proximity to markets is also essential for successful aquaculture development. All observed locations are more than 12km from the nearest market, with the primary market located in Ternate City, approximately 31.56km from the pond areas (Table 2). This does not meet the recommended distance of less than 3km **(Hadipour *et al.*, 2014)**. Similarly, hatchery proximity is critical for production efficiency. Observations show that hatchery units are more than 12km away (Table 2), with most fry sourced from Barru Regency, South Sulawesi Province. This is outside the optimal distance of less than 3km **(Hadipour *et al.*, 2014)**.

Water quality parameters also directly affect fish growth, production, quality, and profitability **(Tumwesigye *et al.*, 2022)**. Among these, temperature is a key factor, influencing growth, reproduction, and behavior **(Volkoff & Rønnestad, 2020)**. Observed water temperatures ranged from 29.83 to 30.33°C (Table 2), which is within the optimal range of 28– 33°C **(National Standardization Agency of Indonesia, 2014)**.

Salinity, the concentration of dissolved salts in seawater, is crucial for the osmoregulation of aquatic organisms and significantly affects shrimp growth and survival **(Anufriieva & Shadrin, 2023)**. Observations recorded salinity levels from 14.33 to 28.00ppt (Table 2), within the optimal range of 5– 40ppt **(Ministry of Marine Affairs and Fisheries, 2016)**.

Dissolved oxygen (DO) is vital for aquatic life, affecting survival, growth, and health **(Li *et al.*, 2022)**. Recorded DO levels ranged from 4.93 to 6.40mg/ L (Table 2), aligning with the optimal range of 5– 7mg/ L **(Ministry of Marine Affairs and Fisheries, 2016)**.

pH, defined as the negative logarithm of hydrogen ion concentration, is another critical factor **(Tsai *et al.*, 2022)**. The ideal pH for aquaculture is between 6.5 and 8.5 **(Dos Santos *et al.*, 2020)**. In this study, water pH ranged from 7.22 to 7.96 (Table 2), meeting the optimal range for the Pacific white shrimp of 7–8.5 **(National Standardization Agency of Indonesia, 2014)**.

Total ammonia nitrogen (TAN) and nitrite are toxic at high concentrations, causing stress, organ damage, and mortality in aquatic species **(Kir & Sunar, 2018; Thorarensen *et al.*, 2023; Zhang *et al.*, 2023)**. Observed TAN values ranged from 0.308

to 1.112mg/ L (Table 2). While most were within the optimal limit of < 0.1mg/ L **(National Standardization Agency of Indonesia, 2014)**, the Tewe site recorded 1.112mg/ L—exceeding the optimal range but still tolerable (< 1.25mg/ L) **(Sun *et al.*, 2023)**. Nitrite levels ranged from 0.018 to 0.026mg/ L (Table 2), well within the standard of < 0.5mg/ L **(Gross *et al.*, 2004)**.

Hydrogen sulfide, a toxic gas lethal even at low concentrations, can also cause odor problems **(Smith & Oseid, 1972)**. Recorded levels were < 0.001mg/ L (Table 2), within the safe limit of < 0.01mg/ L **(Ministry of Environment, 2004)**.

Heavy metals such as mercury, lead, and cadmium negatively affect fish growth and reproduction **(Ray & Vashishth, 2024)**. Mercury levels ranged from 0.0001 to 0.0005mg/ L (Table 2), within the optimal 0–0.019mg/ L **(National Standardization Agency of Indonesia, 2009)**. Lead levels ranged from 0.0058 to 0.0108mg/ L, within the safe limit of < 0.1mg/ L **(National Standardization Agency of Indonesia, 2009)**. Cadmium levels ranged from 0.0013 to 0.0024mg/ L (Table 2), within the optimal 0–0.016mg/ L **(National Standardization Agency of Indonesia, 2009)**.

Soil pH is equally important, influencing pond conditions and species health **(Ritvo *et al.*, 2003; Shafi *et al.*, 2021)**. Observations ranged from 4.08 to 7.50 (Table 2). The optimal range for aquaculture is 6.5–7.5 **(Vinothkumar *et al.*, 2018)**. Most sites—including Toniku (4.42), Tewe (4.33), Dodinga (4.50), Payo (4.08), Bobo (4.50), and Ibu (4.50)—were acidic, though still above the lethal threshold of pH 3.7 for shrimp **(Allan & Maguire, 1992)**.

The conditions of infrastructure, water quality, and soil quality ultimately determine aquaculture development potential. Ideally, development should be based on land suitability conditions **(Mustafa *et al.*, 2022)**, as demonstrated in the intensive Pacific white shrimp projects in Barru Regency (2,399 ha) and the supra-intensive systems in Takalar, Jeneponto, and Bulukumba Regencies **(Tantu *et al.*, 2019; Mustafa *et al.*, 2023)**.

The site assessment results show: Toniku (TU), 70.06 ha, moderately suitable (S2) (Fig. 1); Tewe (TE), 55.70 ha, moderately suitable (S2) (Fig. 2); Dodinga (DA), 27.52 ha, moderately suitable (S2) (Fig. 3); Tuada (TA), 96.39 ha, highly suitable (S1) (Fig. 4); Payo (PO), 46.71 ha, moderately suitable (S2) (Fig. 5); Bobo (BO), 39.43 ha, moderately suitable (S2) (Fig. 6); Sahu (SU), 77.34 ha, highly suitable (S1) (Fig. 7); Ibu (IU), 300.40 ha, highly suitable (S1), and 315.36 ha, moderately suitable (S2) (Fig. 8).

Brackish water aquaculture areas classified as S1 have only minor limiting factors that do not significantly reduce productivity. In contrast, S2 areas require additional technological inputs and higher treatment levels **(Anas *et al.*, 2015)**. These findings provide an important reference for developing the Pacific white shrimp aquaculture in West Halmahera Regency, North Maluku Province, Indonesia.

CONCLUSION

The assessment of infrastructure, water quality, and soil quality parameters indicates that the Toniku, Tewe, Dodinga, Tuada, Payo, Bobo, Sahu, and Ibu areas in West Halmahera Regency, North Maluku Province, Indonesia, are suitable for the Pacific white shrimp aquaculture development. The Toniku area covers 70.06 ha, Tewe 55.70 ha, Dodinga 27.52 ha, Tuada 96.39 ha, Payo 46.71 ha, Bobo 39.43 ha, Sahu 77.34 ha, and Ibu a total of 615.76 ha.

REFERENCES

Adorian, T.J.; Jamali, H.; Farsani, H.G.; Darvishi, P.; Hasanpour, S.; Bagheri, T. and Roozbehfar, R. (2019). Effects of probiotic bacteria *Bacillus* on growth performance, digestive enzyme activity, and hematological parameters of Asian sea bass, *Lates calcarifer* (Bloch). Probiotics and Antimicrobial Proteins, 11: 248–255.

Alday-Sanz, V.; Brock, J.; Flegel, T.W.; McIntosh, R.; Bondad-Reantaso, M.G.; Salazar, M. and Subasinghe R. (2020). Facts, truths and myths about SPF shrimp in aquaculture. Reviews in Aquaculture, 12(1): 76–84.

Allan, G.L. and Maguire, G.B. (1992). Effects of pH and salinity on survival, growth and osmoregulation in *Penaeus monodon* Fabricius. Aquaculture, 107(1): 33–47.

Altaff, K. (2020). Indigenous live feed for aqua hatchery larval rearing of finfish and shellfish: A review. International Journal of Zoological Investigations, 6(1): 162–173.

Anas, P.; Sudinno, D. and Jubaedah, I. (2015). Daya dukung perairan untuk budidaya udang vannamei sistem semi intensif dalam pemanfaatan wilayah pesisir Kabupaten Pemalang. Jurnal Penyuluhan Perikanan dan Kelautan, 9(2): 29–46.

Assefa, W.W. and Abebe, W.B. (2018). GIS modeling of potentially suitable sites for aquaculture development in the Lake Tana basin, Northwest Ethiopia. Agriculture & Food Security, 7: 1–15.

Beveridge, M.C. and Brummett, R.E. (2015). Aquaculture and the environment. In: Freshwater Fisheries Ecology, pp. 794–803.

Davis, R.P.; Boyd, C.E.; Godumala, R.; Mohan, A.B.C.; Gonzalez, A.; Duy, N.P.; Sasmita-J, P.G.; Ahyani, N.; Shatova, O.; Wakefield, J.; Harris, B.; McNevin, A.A. and Davis, D.A. (2022). Assessing the variability and discriminatory power of elemental fingerprints in whiteleg shrimp *Litopenaeus vannamei* from major shrimp production countries. Food Control, 133: 108589.

Dos Santos, J.A.; Soares, C.M. and Bialetzki, A. (2020). Effects of pH on the incubation and early development of fish species with different reproductive strategies. Aquatic Toxicology, 219: 105382.

FAO (2024). The State of World Fisheries and Aquaculture 2024. Blue transformation in action. Rome.

Gross, A.; Abutbul, S. and Zilberg, D. (2004). Acute and chronic effects of nitrite on white shrimp, *Litopenaeus vannamei*, cultured in low-salinity brackish water. Journal of the World Aquaculture Society, 35(3): 315–321.

Hadipour, A.; Vafaie, F. and Hadipour, V. (2015). Land suitability evaluation for brackish water aquaculture development in coastal area of Hormozgan, Iran. Aquaculture International, 23: 329–343.

Hossain, M.S. and Das, N.G. (2010). GIS-based multi-criteria evaluation to land suitability modelling for giant prawn (*Macrobrachium rosenbergii*) farming in Companigonj Upazila of Noakhali, Bangladesh. Computers and Electronics in Agriculture, 70(1): 172–186.

Hukom, V.; Nielsen, R.; Asmild, M. and Nielsen, M. (2020). Do aquaculture farmers have an incentive to maintain good water quality? The case of small-scale shrimp farming in Indonesia. Ecological Economics, 176: 106717.

Kir, M. and Sunar, M.C. (2018). Acute toxicity of ammonia and nitrite to sea bream, *Sparus aurata* (Linnaeus, 1758), in relation to salinity. Journal of the World Aquaculture Society, 49(3): 516–522.

Kumar, M.; Chadha, N.K.; Prakash, S.; Pavan-Kumar, A.; Harikrishna, V.; Gireesh-Babu, P. and Krishna, G. (2024). Salinity, stocking density, and their interactive effects on growth performance and physiological parameters of white-leg shrimp, *Penaeus vannamei* (Boone, 1931), reared in inland ground saline water. Aquaculture International, 32(1): 675–690.

Li, D.; Zou, M. and Jiang, L. (2022). Dissolved oxygen control strategies for water treatment: a review. Water Science & Technology, 86(6): 1444–1466.

Ministry of Environment. (2004). Peraturan Menteri Lingkungan Hidup No. 51/PERMEN-LH/2004 tentang kebijakan dan kelembagaan lingkungan hidup mutu air laut untuk biota laut [Regulation of the Minister of Environment No. 51/PERMEN-LH/2004 concerning marine water quality standards for marine biota]. Jakarta, Indonesia.

Ministry of Marine Affairs and Fisheries. (2016). Peraturan Menteri Kelautan dan Perikanan No. 75/PERMEN-KP/2016 tentang pedoman umum pembesaran udang windu (*Penaeus monodon*) dan udang vaname (*Litopenaeus vannamei*) [Regulation of the Minister of Marine Affairs and Fisheries No. 75/PERMEN-KP/2016 concerning general guidelines for the cultivation of black tiger shrimp (*Penaeus monodon*) and Pacific white shrimp (*Litopenaeus vannamei*)]. Jakarta, Indonesia.

Mustafa, A.; Paena, M.; Athirah, A.; Ratnawati, E.; Asaf, R.; Suwoyo, H.S.; Sahabuddin, S.; Hendrajat, E.A.; Kamaruddin, K.; Septiningsih, E.; Sahrijanna, A.; Marzuki, I. and Nisaa, K. (2022). Temporal and spatial analysis of coastal water quality to support application of whiteleg shrimp *Litopenaeus vannamei* intensive pond technology. Sustainability, 14(5): 2659.

Mustafa, A.; Syah, R.; Paena, M.; Sugama, K.; Kontara, E.K.; Muliawan, I.; Suwoyono, H.S.; Asaad, A.I.J.; Asaf, R.; Ratnawati, E.; Athirah, A.; Makmur, M.; Suwardi, S. and Taukhid, I. (2023). Strategy for developing whiteleg shrimp (*Litopenaeus vannamei*) culture using intensive/super-intensive technology in Indonesia. Sustainability, 15(3): 1753.

Muthu, C.M.; Vickram, A.S.; Sowndharya, B.B.; Saravanan, A.; Kamalesh, R. and Dinakarkumar, Y. (2024). A comprehensive review on the utilization of probiotics in aquaculture towards sustainable shrimp farming. Fish & Shellfish Immunology, 109459.

N'Souvi, K. and Sun, C. (2025). Do exports and domestic prices influence aquaculture shrimp production: Evidence from the key South and Southeast Asian countries. Aquaculture International, 33(1): 1–21.

National Standardization Agency of Indonesia (BSN). (2009). SNI 7387:2009. Batas cemaran logam berat dalam makanan [SNI 7387:2009. Maximum limits of heavy metal contaminants in food]. Jakarta, Indonesia.

National Standardization Agency of Indonesia (BSN). (2014). SNI 8037.1:2014. Udang vaname (*Litopenaeus vannamei*, Boone 1931). Produksi induk model indoor [SNI 8037.1:2014. Pacific white shrimp (*Litopenaeus vannamei*, Boone 1931). Indoor broodstock production model]. Jakarta, Indonesia.

Purnomo, A.R.; Patria, M.P.; Takarina, N.D. and Karuniasa, M. (2022). Environmental impact of the intensive system of vannamei shrimp (*Litopenaeus vannamei*) farming on the Karimunjawa-Jepara-Muria biosphere reserve, Indonesia. International Journal on Advanced Science, Engineering and Information Technology, 12(3): 873–880.

Ray, S. and Vashishth, R. (2024). From water to plate: Reviewing the bioaccumulation of heavy metals in fish and unraveling human health risks in the food chain. Emerging Contaminants, 100358.

Ritvo, G.; Avnimelech, Y. and Kochba, M. (2003). Empirical relationship between conventionally determined pH and in situ values in waterlogged soils. Aquacultural Engineering, 27(1): 1–8.

Shafi, J.; Waheed, K.N.; Mirza, Z.S. and Zafarullah, M. (2021). Assessment of soil quality for aquaculture activities from four divisions of Punjab, Pakistan. JAPS: Journal of Animal & Plant Sciences, 31(2): 556–566.

Smith, L.L. and Oseid, D.M. (1972). Effects of hydrogen sulfide on fish eggs and fry. Water Research, 6(6): 711–720.

Sun, Z.; Wang, S.; Zhang, M.; Jiang, H. and Li, M. (2023). Chronic toxicity study of ammonia exposure in juvenile yellow catfish *Pelteobagrus fulvidraco*. Aquaculture, 567: 739266.

Tamrin, T.; Schaduw, J.N.W.; Sambali, H.; Wantasen, A.S.; Mantiri, D.M.H.; Kepel, R.C.; Mingkid, W.M. and Kalesaran, O.J. (2024). Land suitability analysis for brackishwater aquaculture development in the coastal area of District West Halmahera, Indonesia. AACL Bioflux, 17(1): 440–448.

Tantu, A.G.; Salam, S.; Indrawati, E. and Ayu, A.R.P. (2019). Land suitability analysis of white shrimp (*Litopenaeus vannamei*) aquaculture in the coastal area of Barru District, South Sulawesi–Indonesia. Fish Scientiae, 9(1): 3–23.

Thorarensen, H.; Imsland, A.K.D. and Monroe, A.C. (2023). The effect of CO_2, total ammonia nitrogen and pH on growth of juvenile lumpfish (*Cyclopterus lumpus*). Aquaculture, 577: 739986.

Tsai, K.L.; Chen, L.W.; Yang, L.J.; Shiu, H.J. and Chen, H.W. (2022). IoT-based smart aquaculture system with automatic aerating and water quality monitoring. Journal of Internet Technology, 23(1): 177–184.

Tumwesigye, Z.; Tumwesigye, W.; Opio, F.; Kemigabo, C. and Mujuni, B. (2022). The effect of water quality on aquaculture productivity in Ibanda District, Uganda. Aquaculture Journal, 2(1): 23–36.

Villarreal, H. (2023). Shrimp farming advances, challenges, and opportunities. Journal of the World Aquaculture Society, 54(5): 1092–1095.

Vinothkumar, R.; Aurag, S. and Srinivasan, M. (2018). Analysis of bottom soil quality parameters of shrimp pond culture in modified extensive method. Journal of Emerging Technologies and Innovative Research, 5: 7–12.

Volkoff, H. and Rønnestad, I. (2020). Effects of temperature on feeding and digestive processes in fish. Temperature, 7(4): 307–320.

Zhang, J.M.; Fu, B.; Li, Y.C.; Sun, J.H.; Xie, J.; Wang, G.J.; Tian, J.J.; Kaneko, G. and Yu, E.M. (2023). The effect of nitrite and nitrate treatment on growth performance, nutritional composition and flavor-associated metabolites of grass carp (*Ctenopharyngodon idella*). Aquaculture, 562: 738784.