Growth performance and feed utilization of fish fed seaweed-based feed: a meta-analysis study

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Abstract. Numerous studies have been conducted to determine the effectiveness of adding seaweed to fish feed to enhance fish growth performance. However, the results have been inconclusive, requiring a comprehensive review of relevant research publications. After analyzing 23 relevant publications using a systematic review and meta-analysis approach, it has been determined that adding seaweed to fish feed significantly affects fish growth and utilization.The effect size of weight gain (WG) was determined to be 1.41 (95% CI: 0.19, 2.64; p 0.023; I^2 99.62%), while the specific growth rate (SGR) was found to be 1.53 (95% CI: 0.47; p 0.012; I^2 = 99.68%). Additionally, the effect size of seaweed treatment on feed conversion ratio (FCR) was calculated to be -0.10 (95% CI: -0.16, -0.03; $p < 0.001$; I^2 = 21.401%). Moreover, the effect size of the protein efficiency ratio (PER) was 0.19 (95% CI: 0.09, 0.30; $p < 0.001$; I^2 = 70.35%). Using seaweed in fish feed can significantly improve growth and feed utilization in marine, freshwater, and brackish-water/anadromous/catadromous fish. Among various types of seaweed, green seaweed has been found to have the greatest potential to improve fish growth and feed utilization.

Key Words: seaweed, fish feed, growth performance, feed utilization, meta-analysis.

Introduction. Seaweed is a marine organism that converts carbon dioxide into sugar and oxygen via photosynthesis (Alamsjah et al 2010). Different types of seaweed, such as those in the brown, red, and green seaweed families, supply essential nutrients for fish growth, making them a possible feed item. Based on research, seaweed contains higher-quality protein than cereals and soybean flour (Morais et al 2020). Red seaweed contains 30-40% protein, while brown and green seaweed contain 15% and 30% protein, respectively (Murata & Nakazoe 2001). Seaweed protein comprises amino acids including glycine, alanine, arginine, proline, glutamic acid, and aspartic acid, and the essential amino acids in seaweed account for about half of the total protein amino acids, with a protein profile similar to egg protein (Cerna 2011). Seaweed includes important lipids, the majority of which are long-chain unsaturated fatty acids (Morais et al 2020). Seaweed is also rich in minerals, including macro and microelements like iodine, calcium, salt, selenium, iron, zinc, potassium, and phosphorus (Holdt & Kraan 2010), and a source of vitamins, both water-soluble vitamins (vitamins C and B) and other fat-soluble vitamins (vitamins A and E) (MacArtain et al 2007). Seaweed is also rich in polysaccharides, which are needed to improve fish health (Erniati & Ezraneti 2020).

Studies have shown that seaweed can enhance the growth performance of fish and other animals (Andri et al 2020; Viagem et al 2023). However, the effect of seaweed on fish growth performance is inconsistent, making it difficult to conclude. As a result, it is required to conduct a more objective, complete, and accurate assessment of seaweed's potential as a fish feed element and its impact on fish growth. The meta-analysis approach is currently widely utilized to integrate and assess the overall effect of interventions from multiple studies, resulting in more accurate results (Andri et al 2020). A meta-analysis of the usage of seaweed as a fish feed ingredient has been reported (Viagem et al 2023), but little is known about the effect of seaweed on the growth of various types of fish and which seaweed is most effective in promoting fish growth. As a result, a complete evaluation is required to assess the effect of seaweed inclusion in feed on fish growth performance and feed utilization using a meta-analysis approach.

This study aims to evaluate the impact of seaweed on fish growth performance and feed efficiency using meta-analysis methods.

Material and Method. The meta-analysis in this paper starts by establishing criteria for selecting relevant literature, conducting literature searches, gathering data, and finally analyzing it.

Determining criteria and literature search. Literature searches were conducted in scientific databases of international journals such as Google Scholar, Palgrave Journals/Springer Link, Proquest, and Science Direct. The keywords used for searching were "Seaweed", "Macroalgae", and not "Microalgae", as well as "Growth Performance", "Feed Utilization", and "Fish". The publications obtained were required to meet the following criteria: (1) They must be in English; (2) They must report the types of seaweed and fish used in the research; (3) They must report feed treatments given to seaweed or its derivative products and controls not given seaweed; (4) They must include growth performance parameters such as weight gain (WG) and specific growth rate (SGR), as well as feed utilization parameters such as feed conversion (FCR) and protein efficiency ratio (PER). The publications meeting the criteria are from 2000 to 2023, from various countries, and contain quantitative and qualitative data needed for meta-analysis work. The research was conducted from January 3rd to April 30th, 2024, in Yogyakarta.

Data collection and analysis. The study involved extracting mean values, standard deviations, and sample sizes from each included research paper and tabulating them in Microsoft Excel 2019. The targeted variables in this study were WG, SGR, FCR, and PER. If a research paper used standard error as a measure of variance, it was first converted to standard deviation. Measurements of seaweed subgroups were differentiated based on their nutritional significance and biochemical composition, such as brown, red, green, or mixed seaweed. Similarly, measurements of fish species were differentiated based on their habitat, such as marine, freshwater, and brackish water fish. In the case of using more than one type of seaweed in one research paper, each treatment was assigned a "number" code. If a publication contained different treatment doses, the data with the best value of the treatment results was chosen.

The data analysis was performed using JASP Software version 0.95.1. The effect size estimates, which represent the difference between the seaweed addition and the control group, were analyzed using a random effects model, specifically the Restricted Maximum Likelihood method. A significant effect was considered to be present when the overall estimated effect size had a p-value of less than 0.05. The interpretation of the effect size results was based on the work of Afandi et al (2021).

Results. A comprehensive search across four online databases identified 6,532 publications that matched the given keywords. Following a thorough screening of these publications based on data adequacy, 23 publications were selected for inclusion in the meta-analysis process. The sections of the meta-analysis included the study name, fish species, types of seaweed, and the level of seaweed usage in feed (refer to Table 1 for more information).

Table 1

Data included for meta-analysis

Common name of fish	*Scientific name of fish*	*Subgroup 1*	*Name of seaweed*	*Subgroup 2*	*References*
Barramundi	*Lates calcarifer* (Bloch, 1790)	Marine fish	*Sargassum polycystum*	Brown seaweed	Nazarudin et al 2020
Bastard Halibut	*Paralichtys olivaceus*	Marine fish	*Sargassum fulvellum*	Brown seaweed	Ragaza et al 2021
White spotted spinefoot	*Siganus Canaliculatus* (Park, 1797)	Marine fish	*Gracillaria lemaneiformis*	Red seaweed	Xu et al 2011
Rainbow trout	*Oncorhynchus mykiss* (Walbaum 1792)	Marine fish	*Porphyra dioica*	Red seaweed	Soler-Vila et al 009
North African Catfish	*Clarias gariepinus* (Burchell, 1822)	Freshwater fish	*Ulva lactuca*	Green seaweed	Abdel-Warith et al 2016
Spotted scat	*Scatophagus argus* (Linnaeus, 1766)	Marine fish	*Ulva* sp.	Green seaweed	Yangthong & Ruensirikul 2022
Roho Labeo	*Labeo rohita*	Freshwater fish	*Halynema dilatata*	Red seaweed	Manikandan et al 2022
European Seabass	*Dicenthrarchus labrax*	Marine fish	*Pterocladia capillacea, Ulva lactuca*	Red seaweed, green seaweed	Wassef et al 2013
Rainbow trout	*Oncorhynchus mykiss* (Walbaum 1792)	Marine fish	*Ulva intestinalis, Gracillariopsis persica*	Green seaweed, sed seaweed	Safavi et al 2019
Nile Tilapia x Mozambique Tilapia	*Oreochromis niloticus x Oreochromis mossambicus* (Peters 1852)	Freshwater fish	*Laurencia obtusa*	Red seaweed	Salem et al 2021
Barramundi	*Lates calcarifer* (Bloch, 1790)	Marine fish	*Gracillaria pulvinata*	Red seaweed	Morshedi et al 2018
Barramundi	*Lates calcarifer* (Bloch, 1790)	Marine fish	*Sargassum spinosum, Padina australis*	Brown seaweed	Morshedi et al 2023
Rainbow trout	*Oncorhynchus mykiss* (Walbaum 1792)	Marine fish	*Ulva rigida*	Green seaweed	Güroy et al 2013
Barramundi	*Lates calcarifer* (Bloch, 1790)	Marine fish	*Kappaphycus alvarezii, Euchema denticulatum, Sargassum polycystum*	Red seaweed, brown seaweed	Shapawi & Zamry 2016

Barramundi	*Lates calcarifer* (Bloch, 1790)	Marine fish	*Kappaphycus alvarezii*	Red seaweed	Shapawi et al 2015
Nile Tilapia	*Oreochromis niloticus*	Freshwater fish	*Ulva rigida*	Green seaweed	Ergün et al 2009
Bastard Halibut	*Paralichtys olivaceus*	Marine fish	*Ulva lactuca* + *Soliera chordalis*	Mix seaweed	Tharaka et al 2020
Nile Tilapia	*Oreochromis niloticus*	Freshwater fish	*Ulva spp., Gracillaria vermiculophylla, Porphyra dioica*	Green seaweed, red seaweed	Silva et al 2015
Nile Tilapia	*Oreochromis niloticus*	Freshwater fish	*Taonia atomaria*	Brown seaweed	Hussein 2017
European Seabass	*icenthrarchus labrax*	Marine fish	*Ulva sp.* + *Gracillaria gracilis*	Mix seaweed	Mota et al 2023
Atlantic Salmon	*Salmo salar* (Linnaeus 1758)	Brackishwater/anadromous/catadromous fish	Alginate Oligosaccharide	Brown seaweed	Sarfo 2017
Flathead greu mullet	*Mugil cephalus* (Linnaeus 1758)	Brackishwater/anadromous/catadromous fish	*Gracillaria arcuata*	Red seaweed	Akbary et al 2020
Nile Tilapia	*Oreochromis niloticus*	Freshwater fish	*Ulva fasciata*	Green seaweed	Saleh et al 2014

Subgroup 1: Type of fish habitat
Subgroup 2: Type of Seaweed

The effect of seaweed inclusion in feed on the fish growth and utilization of feed. The inclusion of seaweed to fish feed has a significant impact on fish growth, demonstrated by improvement in WG and SGR, as well as fish feed utilization measured by FCR and PER ($p < 0.05$). In particular, the inclusion of seaweed to fish feed leads to a substantial increase in fish growth, as evident in the summary effect size of WG, which was 1.41 (95% CI: 0.19, 2.64; p 0.023; I^2 99.62%) (Figure 1), and the effect size of SGR was 1.53 (95% CI: 0.47; p 0.012; I^2 99.68% (Figure 2).

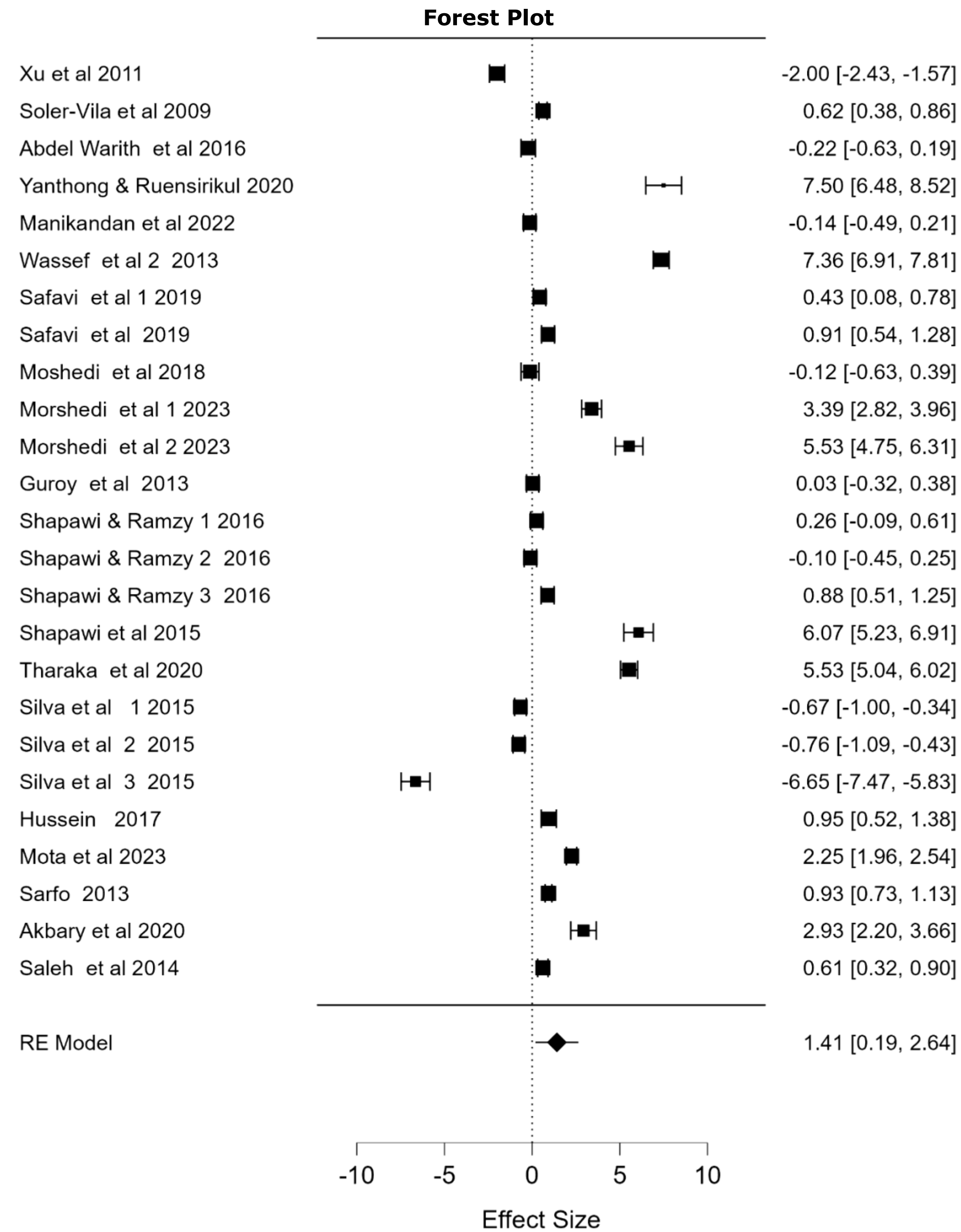

Figure 1. The effect size of WG of fish fed seaweed-based feed. A Positive value shows a higher value of the treatments than the control, and vice versa.

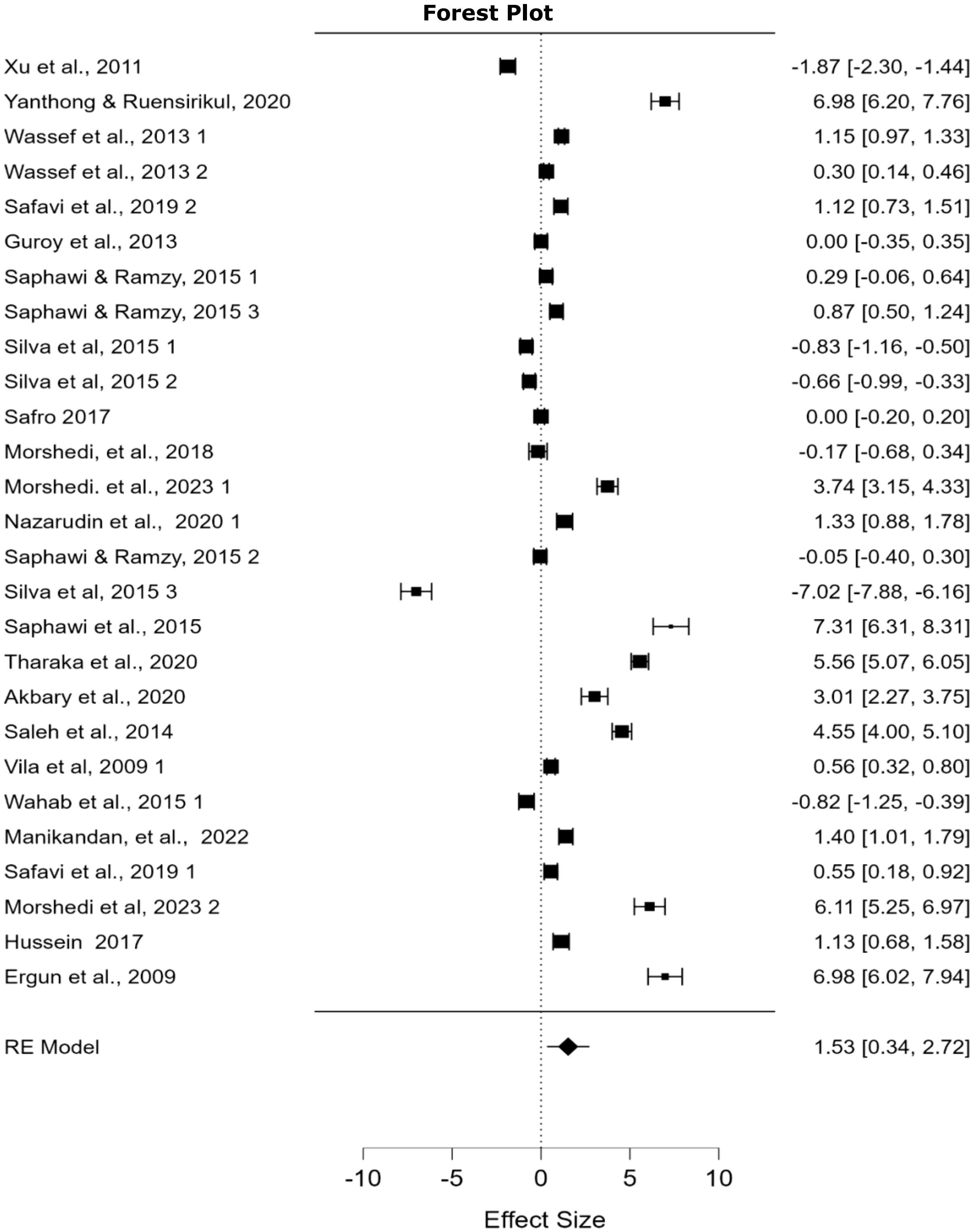

Figure 2. The effect size of SGR of fish fed seaweed-based feed. A Positive value shows a higher value of the treatments than the control, and vice versa

The study found that the inclusion of seaweed in fish feed had a significant positive effect on FCR and PER ($p < 0.05$). The effect size value of seaweed treatment on FCR was -0.10 (95% CI: -0.16, -0.03; $p < 0.001$; $I^2 = 21.401\%$), indicating that the FCR for treatments is lower than that for the control (Figure 3). Meanwhile, the effect size value for PER was 0.19 (95% CI: 0.09, 0.30; $p < 0.001$; $I^2 = 70.35\%$) (Figure 4).

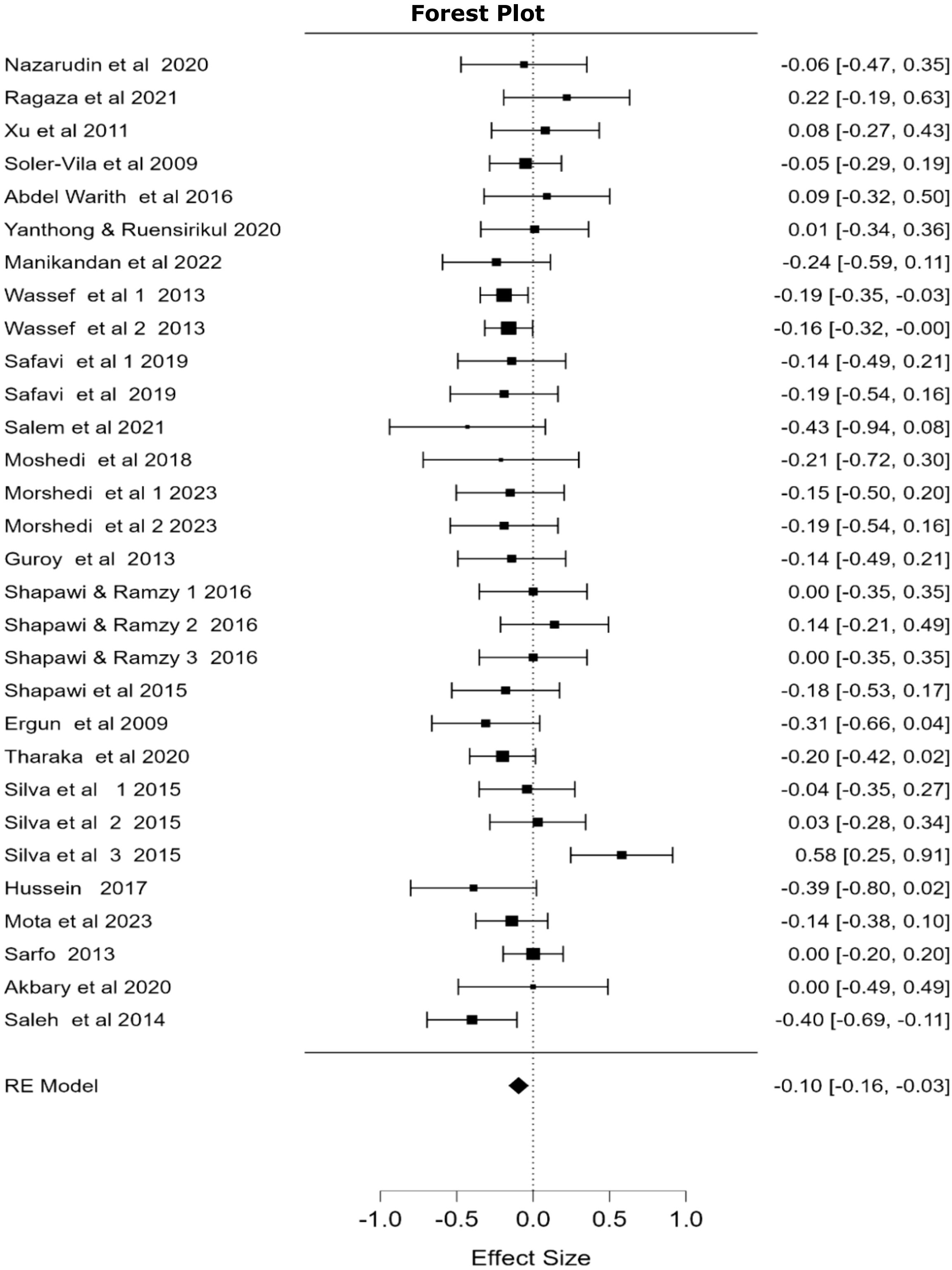

Figure 3. The effect size of FCR of fish fed seaweed-based feed. A positive value shows a higher value of the treatments than the control, and vice versa.

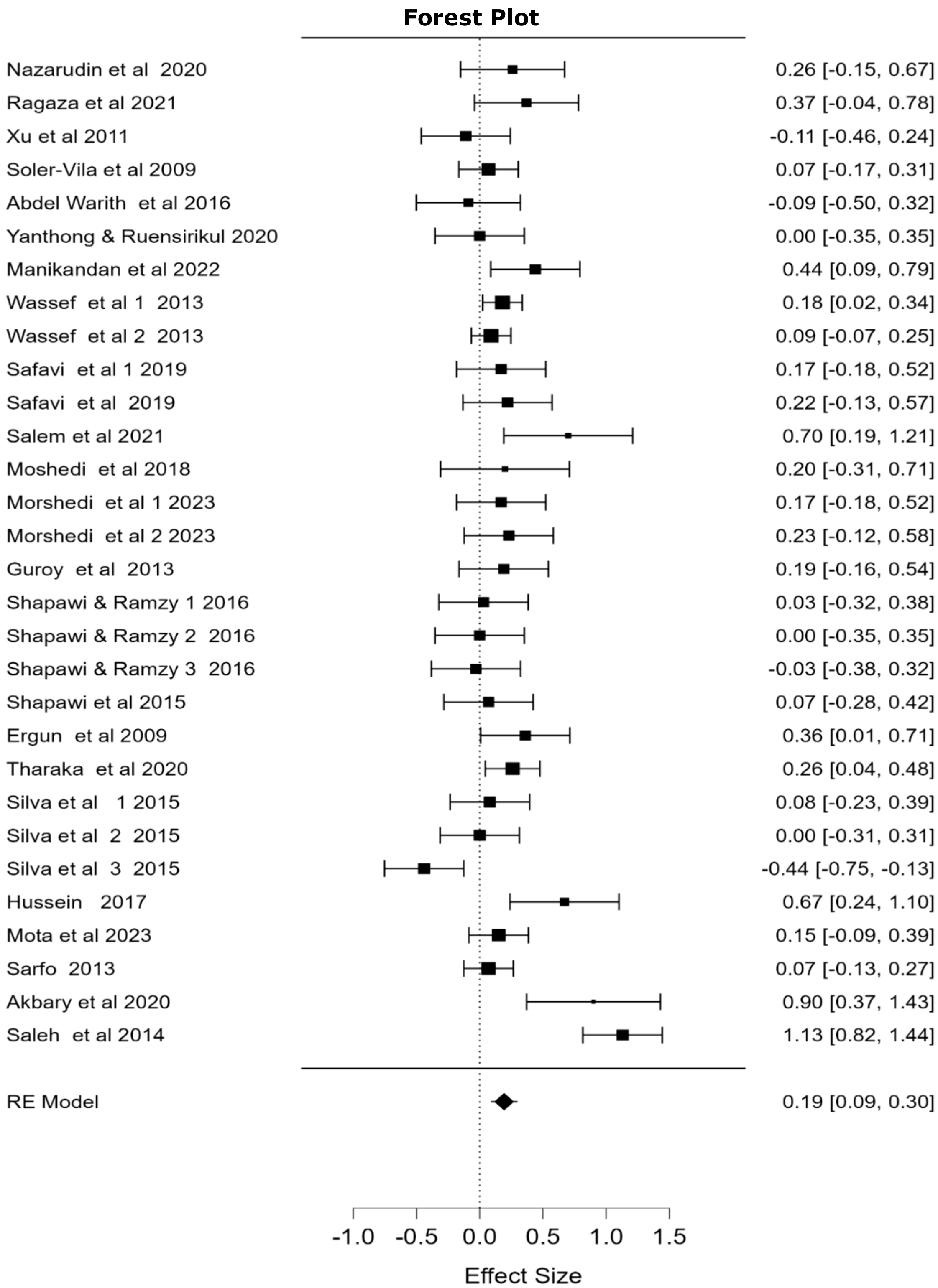

Figure 4. The effect size of PER of fish fed seaweed-based feed. A positive value shows a higher value of the treatments than the control, and vice versa.

The effect of seaweed-based feed on fish species. The inclusion of seaweed in fish feed significantly impacted the SGR for both marine and freshwater fish ($p < 0.05$). For marine fish, the effect size was 2.212, with a 95% confidence interval of 0.928 to 3.496 ($p < 0.001$; $I^2 = 99.654\%$). In contrast, the inclusion of seaweed in the feed for freshwater fish did not have the same positive effect on SGR. In fact, the effect size for freshwater fish was negative, suggesting that the SGR value for the treatment group was lower than that of the control group. The effect size for freshwater fish was -0.312, with a 95% confidence interval of -2.902 to 2.278 ($p < 0.001$; $I^2 = 99.608\%$) (see Table 2). The information regarding the effect size of SGR in brackishwater fish was unavailable; therefore, it cannot be calculated.

Seaweed inclusion in the fish diet also significantly increased the WG value of marine fish ($p < 0.05$), but it has no significant impact on the WG of brackishwater and freshwater fish ($p > 0.05$). The effect size value for marine fish was 2.393 (95% CI: 0.911, 3.876; $p < 0.002$; I^2=99.537%), for brackishwater fish it was 1.898 (95% CI: -0.061, 3.857 ; p 0.058; I^2 = 99.328%) and for freshwater fish it was -0.966 (95% CI: -2.846, 8.915; $p < 0.000$; I^2 = 99.420%) (Table 2).

Table 2

The effect size of the WG, SGR, FCR, and PER parameters for three types of fish, based on their habitat, after being fed a diet containing seaweed. A positive value shows a higher value of the treatments than the control, and vice versa

Parameters	*Type of fish*	*Estimate*	*I^2 (%)*	*z*	*p*	*95% confidence interval*	
						Lower	*Upper*
WG	Marine fish	2.393	99.537	3.160	0.002	0.911	3.876
	Brackishwater fish	1.898	96.328	1.910	0.058	-0.065	3.857
	Freshwater fish	-0.966	99.420	1.010	0.314	-2.846	0.915
SGR	Marine fish	2.212	99.654	3.38	<0.001	0.928	3.496
	Brackishwater fish	-	-	-	-	-	-
	Freshwater fish	-0.312	99.608	-0.24	0.813	-2.902	2.278
FCR	Marine fish	-0.115	0.0000	-1.534	<0.001	-0.179	-0.051
	Brackishwater fish	0.000	0.0000	0.000	1.000	-0.182	0.182
	Freshwater fish	-0.113	70.012	-2.507	0.308	-0.330	-0.104
PER	Marine fish	0.134	0.0000	1.965	<0.001	0.070	0.198
	Brackishwater fish	0.447	87.966	1.676	0.279	-0.363	1.057
	Freshwater fish	0.309	86.067	2.963	0.058	-0.010	0.628

Marine fish that were fed a diet based on seaweed showed a significantly lower FCR compared to the control group ($p < 0.05$) (see Table 2). In contrast, freshwater fish also exhibited a lower FCR, but the difference was not statistically significant when compared to the control group ($p > 0.05$). The effect size value for marine fish was – 0.115 (95% CI: -0.179, -0.051; $p < 0.001$; I^2 = 0.000%), while for freshwater fish it was -0.113 (95% CI: -0.330, 0.104; $p = 0.308$; I^2 = 70.012%). The FCR effect size values for brackishwater fish are not depicted in the table. This is because the publications included in the calculation have the same FCR values and standard deviation between the treatment and the control. Therefore, during the calculation, they are considered as missing values.

Fish groups from marine environments that were fed a seaweed-based diet showed higher PER values, which were significantly different from those of the control ($p < 0.05$) (see Table 2). In contrast, freshwater and brackishwater fish that received the same treatment also displayed higher PER values compared to the control group; however, this difference was not statistically significant. The group of brackishwater fish showed the highest effect size value of PER at 0.447 (95% CI: -0.363, 1.257; $p < 0.279$; I^2 = 87.966%), followed by the freshwater fish group at 0.309 (95% CI: -0.010, 0.628; p = 0.058; I^2 = 86.067%). The marine fish group had the lowest effect size value of PER at 0.134 (95% CI: 0.070, 0.198; $p < 0.001$; I^2 = 0.000%) (Table 2).

Effect of using different types of seaweed on fish growth. According to the study, fish can grow better when fed seaweed. There are four types of seaweed in the group: brown seaweed, red seaweed, green seaweed, and a combination of both green and red seaweed (mix seaweed). The SGR of the red, brown, and mixed seaweeds did not show significant differences between the treatment and control groups ($p > 0.05$). However, the green seaweed had a significant impact on the SGR parameters. Table 3 provides more details information. Meta-analysis of WG parameters revealed different results from SGR. The WG data indicated that brown and mixed seaweeds showed significant differences from the control group ($p < 0.05$). In contrast, red and green seaweeds did not demonstrate a significant difference compared to the control ($p > 0.05$). Among the seaweeds, mixed seaweed exhibited the highest effect size for WG at 3.884, followed by brown seaweed at 2.134, green seaweed at 1.334, and red seaweed at 0.658 (see Table 3).

Table 3

The effect sizes of the WG, SGR, FCR, and PER parameters in fish fed a diet containing different types of seaweed. A positive value indicates that the treatments resulted in higher values compared to the control, while a negative value indicates the opposite

Parameters	*Type of seaweed*	*Estimate*	*I^2(%)*	*z*	*p*	*95% confidence interval*	
						Lower	*Upper*
WG	Green seaweed	1.334	99.577	1.090	0.278	-1.075	3.743
	Red seaweed	0.658	99.678	0.630	0.527	-1.379	2.615
	Brown seaweed	2.314	99.035	2,510	0.012	0.508	4.121
	Mix seaweed	3.884	99.210	2.370	0.018	0.670	7.098
SGR	Green seaweed	3.116	99.750	3.260	0.001	1.036	5.204
	Red seaweed	1.248	99.750	1.450	0.146	-0.550	3.055
	Brown seaweed	-0.424	99.580	-0.240	0.812	-3.214	2.376
	Mix seaweed	4.039	99.144	1.380	0.167	-0.404	8.460
FCR	Green seaweed	-0.172	0.000	-3.380	<0.001	-0.272	-0.072
	Red seaweed	-0.034	46.769	-0.530	0.599	-0.160	0.092
	Brown seaweed	-0.060	0.003	-0.970	0.331	-0.182	0.061
	Mix seaweed	-0.173	0.000	-2.130	0.033	-0.332	-0.014
PER	Green seaweed	0.264	83.059	1.970	0.049	0.001	0.527
	Red seaweed	0.123	67.496	1.500	0.133	-0.037	0.283
	Brown seaweed	0.204	27.464	2.650	0.008	0.053	0.354
	Mix seaweed	0.210	0.0000	2.590	0.010	0.051	0.369

The inclusion of seaweed in fish feed affects the FCR (Table 3). The FCR parameter is a crucial aspect in determining feed efficiency. It is a comparison of feed consumption and weight gain. A decreased FCR ratio suggests higher feed efficiency (Hermawan et al 2014). In this study, all types of seaweed have lower FCR values than the control (Table 3). However, only green seaweed showed a significant difference compared to the control. PER is an indicator to evaluate the quality of feed protein. It is estimated by dividing the test animal's WG by their protein intake (Lamb & Harden 1993). A meta-analysis of PER values revealed that all types of seaweed exhibited a significantly positive effect on fish PER compared to the control, except for red seaweed (see Table 3).

Discussion. Feeding fish with seaweed-based feed can enhance growth, particularly in marine fish, as shown by increased SGR and WG compared to control groups. Additionally, it can improve feed efficiency, indicated by a lower FCR and higher PER than the control. This growth is stimulated by seaweed's nutrient content, which includes protein, amino acids, polysaccharides, fatty acids, vitamins, and minerals (Shapawi et al 2015). Fish require these nutrients for optimal growth. The seaweed-based feed also improves feed protein absorption and assimilation efficiency, lipid metabolism (accumulation and mobilization), and vitamin and trace element content, all of which contribute to fish growth performance (Morshedi et al 2018).

Polysaccharides present in seaweed, particularly sulfated polysaccharides, have been shown in studies to promote growth (Safavi et al 2019). This is because seaweed contains prebiotics, which improve stress tolerance in a variety of fish species (O'Sullivan et al 2010). Prebiotics promote the growth of beneficial bacteria in the digestive tract, boost the immune system, and improve nutritional digestibility, resulting in more effective protein use (Safavi et al 2019). Polysaccharide-containing feed can enhance digestive enzyme activity, resulting in increased nutrient consumption and digestibility, eventually giving rise to improved health and growth conditions (Mohan et al 2016; Peixoto et al 2016).

Effect of seaweed-based feed on different types of fish. Meta-analysis results indicate that the inclusion of seaweed in fish feed has a more significant impact on the growth and feed utilization of marine fish compared to brackish water and freshwater fish. This is likely because seaweed is a marine plant and serves as a natural food source for marine fish. As a result, marine fish have microflora in their digestive tracts that are adapted to digesting seaweed, which is part of their natural diet. Seaweed does not affect marine fish to utilize or absorb feed protein; in fact, it increases the fish's PER value and lowers the FCR. In contrast, the addition of seaweed to feed typically does not significantly impact the growth of freshwater fish or the efficiency of their feed utilization. Wan et al (2016) found that the growth responses of different fish species to seaweed are related to their feeding behavior (herbivore, omnivore, and carnivore) and/or natural habitats such as marine, brackishwater, or freshwater fish. These factors help fish efficiently digest and absorb nutrients from seaweed-based feed, which is related to intestinal structure (Wan et al 2016). The information collected regarding the inclusion of seaweed in feed to promote the growth of brackish water fish in this study is limited. Consequently, measuring key parameters such as the SGR and FCR is difficult, making it challenging to draw any definitive conclusions.

Effect of using different types of seaweed on fish growth. Green seaweed, based on fish SGR, PER, and FCR value, has significantly improved fish growth and feed consumption compared to other seaweeds ($p < 0.05$). The potential of green seaweed to promote growth is due to its nutritional composition and active compounds. Green seaweeds, such as *Ulva lactuca* and *Durvillaea antarctica*, include protein, dietary fiber, lipids, polyunsaturated fatty acids, and provitamin E, making them a nutritious option for both humans and animals (Ortiz et al, 2006). Besides being high in active compounds, green seaweed is also quite digestible. Ulva-type green seaweed has a digestibility of approximately 86% (Demarco 2022). Meanwhile, Nafiqoh et al (2021) found that green seaweed, such as *Ulva* sp., has a greater digestibility than red seaweed (*Gracillaria* sp., 64.79%, and *Palmaria* sp., 66.96%) and brown seaweed (*Sargassum* sp., 66.04%). It is speculated that the high digestibility of green seaweed causes significantly different fish FCR and PER values than controls. This implies that fish feed based on green seaweed, specifically *Ulva* sp., is more effective than feed produced from other seaweed families.

In this study, brown seaweed generally increases the values of WG and PER significantly, while tending to reduce FCR in fish, although this reduction is not statistically significant. According to Zeynaldi et al (2020), brown seaweed such as *Sargassum ilicifolium* and *Padina australis* can boost fish growth by improving gut morphology and structure and boosting digestive enzyme liberation. Brown seaweed also contains chemical compounds that are good for fish health and growth. The *Sargassum* genus of brown seaweed is high in vitamins, carotenoids, dietary fiber, protein, and minerals. It also includes terpenoids, flavonoids, sterols, sulfated polysaccharides, polyphenols, sargaquinoic acid, and sargachromenol, all of which exhibit biological activities such as anti-inflammatory, antioxidant, anti-microbial, and immune-modulatory properties (Yende et al 2014). Active chemicals contained in brown seaweed are thought to stimulate fish appetite, resulting in greater food intake and, eventually, growth. This is backed by a study conducted by Kamunde et al (2019), who discovered that Atlantic salmon fed brown seaweed-based feed ingested more food than the control group. The presence of attractants in seaweed stimulates feed consumption, which is why feed intake has increased.

Red seaweed is reported to have the greatest protein content among seaweeds (Cerna 2011). It also includes sulfated polysaccharides, which trigger an immunological response (Zaitseva et al 2012). However, it may be ineffective in maximizing fish development and feed use. Studies have demonstrated that using *Gracillaria* sp., a species of red seaweed, in feed at a 10% concentration reduced the growth performance of tilapia fish (Silva et al 2015). This may be related to the low level of feed consumption and the presence of anti-nutritional substances, such as saponins, tannins, or phytic acid, which may reduce feed acceptance due to their bitter taste and interfere with lipid and bile salt absorption (Silva et al 2015). According to one study, seaweed high in undigested fiber can affect fish growth and feed consumption (Azaza et al 2008). A recent study found that *Gracillaria* sp. (red seaweed) had a greater fiber content than *Ulva* sp. (green seaweed) and *Sargassum* sp. (brown seaweed) (Nafiqoh et al 2021). It is noteworthy to note, however, that red seaweed can be combined with green seaweed to reduce its limits. It has been found that combining green and red seaweed in feed increases fish weight gain, feed conversion ratio, and protein efficiency ratio. This indicates a synergistic effect between the two seaweeds. The combination of green and red seaweed can improve feed palatability and digestibility, resulting in more effective feed consumption. Furthermore, the combination of each seaweed's good characteristics makes a stronger impact because they both support or complement one another, resulting in higher fish development performance.

Conclusions. According to the meta-analysis results, incorporating seaweed in fish feed can lead to an increase in growth (WG and SGR) and fish feed utilization (FCR and PER) for all types of fish- marine, freshwater, and brackish water/anadromous/catadromous. Among different types of seaweed, the green seaweed group is the most promising option to be used as raw material for feed to enhance fish growth and feed utilization.

Acknowledgements. The authors thank the National Research and Innovation Agency of Indonesia and the Lembaga Pengelola Dana Pendidikan-Ministry of Finance of the Republic of Indonesia, for their support through a Research Grant titled "Riset dan Inovasi Indonesia Maju 3" (RIIM 3) with grant number 12/II.7/HK/2023.

Conflict of interest. The authors declare that there is no conflict of interest.

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Received: 06 May 2025. Accepted: 25 July 2025. Published online: 02 December 2025.
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How to cite this article:
Mulyasari, Subaryono, Afandi F. A., Kusrini E., Kusmini I. I., Noviendri D., 2025 Growth performance and feed utilization of fish fed seaweed-based feed: a meta-analysis study. AACL Bioflux 18(6):2665-2679.