

## A comparison of the technical efficiency of Aquaculture Stewardship Council certified shrimp farms to non-certified farms

Robert P. Davis<sup>a,\*</sup>, Claude E. Boyd<sup>a</sup>

<sup>a</sup> Auburn University, School of Fisheries, Aquaculture, and Aquatic Sciences, 203 Swingle Hall, Auburn, AL 36830, United States of America

### ARTICLE INFO

#### Keywords:

Aquaculture  
Sustainability  
Eco-labeling  
Standardization

### ABSTRACT

Aquaculture will play an increasingly important role in the global seafood supply as fisheries harvests have plateaued. Shrimp are a highly valuable aquaculture commodity which are produced largely for global trade. The Aquaculture Stewardship Council's shrimp certification standard is meant to serve as a market-based tool that rewards the better actors in the industry for improved performance in areas like technical efficiency, social responsibility, and traceability. The goal of this study was to compare production methodology and efficiency of farms currently certified to the ASC shrimp standard to non-certified farms from recent field surveys in the same geographical areas. Certified farms were statistically larger on average (four times larger in Latin America and 10 times larger in Asia). While farms in Asia operate at higher production intensities, no differences were seen due to certification status. No differences were seen in the FCR of farms in Asia, but ASC farms in Latin America had the higher average FCRs than non-certified farms (1.80 vs. 1.33). ASC farms in Asia used drastically less water exchange and were more energy efficient than other farms as well. These findings were used to make recommendations for the ASC standard and certification standards in general, including a greater emphasis on requirements for limits on efficiency-based metrics beyond reporting the outcome of the calculation.

### 1. Introduction

The global demand for edible meat for use in human diets is forecasted to increase at a greater rate than the population over the next 25–30 years (FAO, 2009). The world's capture fisheries production has stagnated over the last three decades (FAO, 2018), and the expected increase in demand for seafood products by the growing population, especially the predicted increase in the global middle class, will have to be met with aquaculture. Aquaculture has been one of the fastest growing protein sources globally, and it has either exceeded or is only slightly less than capture fisheries production for human consumption which has traditionally been the major source of seafood (FAO, 2018; Edwards et al., 2019).

One of the most valuable seafood commodities is farmed penaeid shrimp, which has a value that far exceeds the proportion of tonnage produced (FAO, 2018). The whiteleg shrimp, *Litopenaeus vannamei*, is the most commonly cultured penaeid species globally, accounting for 83% of all penaeid shrimp culture (FAO, 2019). Most of the production is centered in a few countries within Latin America and South East Asia, including Ecuador, Thailand, Vietnam, India, Indonesia, and China

(FAO, 2019). While China is the world's leading producer of whiteleg shrimp, most of its production is for domestic consumption (Zhang et al., 2017). The rest of the production is largely for consumption in global markets, mainly in the EU, the US, and Japan (UN, 2020).

Shrimp production by aquaculture is mired by a history of social and environmental blackmarks. The earliest attempts of intensive shrimp culture in Taiwan collapsed because of poor management and disease problems (Chamberlain, 2010). Others have criticized the expansion of shrimp into coastal areas where it replaced mangrove habitat (Naylor et al., 1998; Primavera, 2006), and have pointed out that shrimp farming was responsible widespread mangrove deforestation in the second half of the 20th century (Giri et al., 2015). Aquaculture in coastal areas has also led to the release of antibiotics in the environment due to careless use in ponds (Holmstrom et al., 2003) and locally diminished water quality (Sansanayuth et al., 1996; Jones et al., 2001). Shrimp farming was also criticized for the use of wild fish meal in shrimp feeds (Naylor et al., 1998; Naylor et al., 2000). Socially, shrimp farming has been criticized for exploiting local labor and disconnecting local communities from natural resources (Bailey, 1988), and has been more recently linked to allegations of forced labor on fishing vessels used for

\* Corresponding author.

E-mail address: [Robert.davis.bd@gmail.com](mailto:Robert.davis.bd@gmail.com) (R.P. Davis).

<https://doi.org/10.1016/j.crsust.2021.100069>

Received 8 March 2021; Received in revised form 9 July 2021; Accepted 10 July 2021

Available online 20 July 2021

2666-0490/© 2021 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

the production of fishmeal in shrimp feeds (Hodal et al., 2014). Nevertheless, shrimp trawling has also caused damage to marine ecosystems. The ills of shrimp aquaculture can be greatly reduced by better farm siting and operations, while those of trawling are more difficult to correct (Clay, 1996), and the penaeid shrimp catch has plateaued (FAO, 2019).

The interest in promoting sustainability in aquaculture and developing best management practices is generally shared amongst environmentalists, industry, and academic institutions. The role of certification schemes is to allow consumers to discern shrimp from well operated shrimp farms from those originating from poorly operated farms and thereby encourage sustainable practices with their purchases. The concept behind certification schemes is that by setting high standards for certification, better actors in the market will be rewarded with better prices and preferential treatment from buyers (Clay, 2008; Roheim et al., 2011; Del Giudice et al., 2018). Over time, certification will theoretically lead to a shift in performance (be it, in resource efficiency, treatment of workers, safety, etc.), towards better performance, thereby improving the standard practices of the industry (see Fig. 1). However, the practice of certification has not existed long enough to demonstrate this pattern.

Developed in a partnership with the World Wildlife Fund (WWF) and the Sustainable Trade Initiative (IDH) through a multi stakeholder process initially known as the aquaculture dialogues (Boyd and McNevin, 2015), the Aquaculture Stewardship Council (ASC) is one of the world's most prominent certification bodies in aquaculture. They have several standards for the certification of common aquaculture products, including the Aquaculture Stewardship Council shrimp standard. Originally crafted in 2015, it includes standards that must be met by a farm for worker's welfare, community engagement, resource efficiency, and environmental responsibility (Aquaculture Stewardship Council, 2014). However, many of the quantitative standards in the shrimp standard [e.g., feed conversion ratio (FCR)], require no target level but simply that the farm maintain records that show calculations were done correctly. This leads one to question one of the underlying assumptions of the ASC certification; that the farms certified represent the better performers. Therefore, the objective of this study was twofold; i. describe the characteristics of the farms certified under the ASC shrimp standard, ii. compare quantitative efficiency metrics from farms certified by the ASC shrimp standard to data recently collected in Southeast Asia (Boyd et al., 2017; Boyd et al., 2018), and Ecuador (Boyd et al., 2021) with field surveys at shrimp farms.

## 2. Methods

Data from the ASC's publicly available certification audits were extracted to create the data for this study. The audits were screened for data in September and October of 2020. Farms culturing exclusively *L. vannamei* that were currently certified within the window of data extraction were included in this survey. The following information, with the location of the information in the audit in parentheses, was extracted for each certification included in the analysis; i. farm name (website), ii. ASC certification number (website), iii. at least one GPS point for the certification (website), iv. country where the farm is located (website), v. farm size (audit opening or Standard 1.1), vi. number of farms (audit opening), vii. Number of ponds (audit opening), viii. Annual production (audit opening), ix. production pond area (ha), x. survival (Standard 5.1.3), xi. Production system (coded as 1, 2, or 3 in Standard 5.1.3, they are non-fed non-aerated, fed but not permanently aerated, and fed and permanently aerated, respectively), xii. The feed fish equivalence ratio (FFER, Standard 7.4.1), xiii. Feed conversion ratio (FCR, 7.4.2), xiv. Water exchange rate (Standard 7.5.1), xv. Nitrogen load in N/t shrimp (Standard 7.5.1), xvi. Phosphorus load (7.5.2), xvii. Direct energy use (7.6.2), and xviii. Any chemicals used at the farm (Standard 7.7.1) were also obtained.

In the case of multisite certifications cumulative statistics (e.g., production, farm size), the sum of all the farms in the certification is reported. In the case of FFER, FCR, survival, N load, P load, water exchange rate, and energy use, the average values of multisite certifications were used. The audit templates allow for the farm to report an estimated annual production and actual production totals from previous years. The estimated annual production from the farm is often over-estimated in the audits, therefore when available the most recent year of production was used as the production total for the farm. If no production data was available and only the estimate provided by the farm was available, then this was used instead of the actual production. In the case where the total farm area was not reported but the total production area was, the total production area was used as the farm area to serve as an estimate, although the authors recognize this underestimates the total area of the farm. The audit was considered the unit of replication for all statistical procedures that followed. The production intensity was calculated as the annual production/production area (t/ha/yr) when both statistics were available for an audit, and not included in statistical procedures when one or both measures required to calculate production intensity were not available. The most recent complete audit report was used to collect data in the case where multiple audits were available.

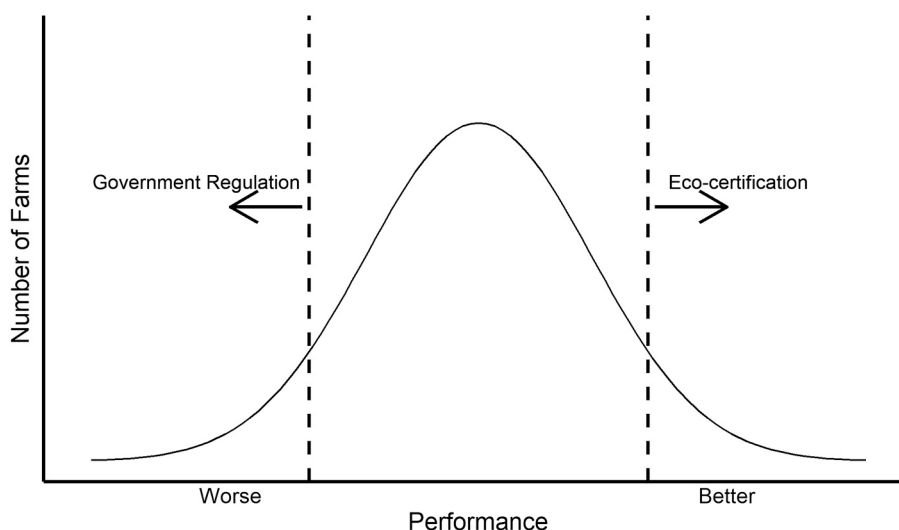


Fig. 1. A conceptual model of change for eco-label certification based on the variation in performance of key metrics, adapted from Clay (2008).

## 2.1. Statistics

The mean values for all numeric values obtained from the audits were averaged and reported by country. The cumulative production and land area certified in each country was totaled and presented alongside the total production for *L. vannamei* according to FAO's fishstat software (FAO, 2019) and the land totals were taken from Boyd and McNevin (2018) adjusted with land:water ratios (LWR) for each country from Jescovitch et al. (2016). The data from Boyd and McNevin (2018) and the FAO are estimates compiled mostly from government sources. These, along with the estimates for LWR in Jescovitch et al., 2016, are the best available estimates for the relevant statistics, however there is some uncertainty in these values. They are presented to provide context with the ASC data, and not serve as absolute values for production and production area.

The data from the ASC audits were subsequently compared to data presented in Boyd et al. (2017), Boyd et al. (2018), and Boyd et al. (2021). The countries included from the non-certified surveys include Ecuador ( $n = 101$ ), India ( $n = 100$ ), Thailand ( $n = 34$ ), and Vietnam ( $n = 45$ ). For FCR, Two-way ANOVA was used to analyze the effect of region (coded as Latin America and Asia for the ASC and non-ASC farms) and certification as well as the interaction. The following variables were compared: average farm size, production, production intensity, FCR, water exchange rate, and energy use. In the case of significant differences, post-hoc comparisons were made utilizing Tukey's highly significant differences  $p$  value adjustment (Norman and Streiner, 2014). For all other variables compared statistically (average farm size, annual production, production intensity, water exchange, and direct energy use), a non-parametric rank based procedure outlined in Wobbrock et al. (2011) was used utilizing the R package "ARTool" for the purposes of comparing country  $\times$  certification status means. The post hoc comparisons were then completed on the ranks of the variables in each group. Chi-Square Tests were used to determine if any relationship existed between reported chemical use and certification status in Asia and in Latin America (certified vs non-certified in each region). An alpha of 0.05 was used for all tests of significance. All statistical analyses were conducted in R version 3.6.2 (R Core Team, 2019).

## 3. Results

Altogether, there were 123 farm audits that strictly culture *L. vannamei* in the ASC auditing data during the time of data screening, with most of the farms occurring in Asia. The Latin American countries, where there are certified farms, have a relatively high percentage of production covered from certification, ranging from 3.26% in Mexico to 94.56% in Honduras (Table 1). The countries from Asia where farms are certified have far less production under certification, ranging from

0.02% in Indonesia to 3.41% in Vietnam. Altogether, 4.14% of global production of *L. vannamei* is certified under the ASC standard. Based on data in the audit reports, Ecuador has the most area of land under certification with over 22,000 ha certified, roughly 45% of the total land for *L. vannamei* farms certified under the ASC Shrimp standard. Other countries with a high proportion of certified area relative to the total area in the country include Honduras, Guatemala, and Venezuela, although these countries do not contribute greatly to global production.

The countries with the most certified farms were India (36), Ecuador (27), and Thailand (25) (Table 2). The type of farm system used in Asia was dominated by permanently aerated fed systems (50 out of 54 reported), while the prevalent system in Latin America was the non-permanently aerated, fed system (47 out of 48 reported). Only one certification was for a farm described as extensive (non-fed, non-aerated), which was in Vietnam. Survival rates were on average higher in Asia countries (ranging from 54.8% in China to 85.6% in India) as compared to Latin American countries (ranging from 35.0% in Panama to 66.6% in Guatemala). Additionally, the FFER of farms in Latin America was generally higher (ranging from 0.20 in Nicaragua to 0.73 in Ecuador) than Asian countries (ranging from 0.0 in Thailand to 0.81 in Indonesia). This was driven by many farms in Asia utilizing feeds in which fisheries by-products were substituted as the fish meal source; these byproducts do not count towards the FFER calculations in the ASC shrimp standards.

ASC farms were significantly larger than the non-certified counterparts as revealed from recent data obtained from field surveys, with the ASC farms in Asia being 10 times larger on average than non-certified farms (Table 3, Fig. 2a). Farms from Latin America were on average a greater size than farms from Asia, and ASC certified farms were more than four times larger than non-certified farms in Latin America ( $\bar{x} = 615$  vs 149 ha, respectively). Annual production was similar, with ASC farms in Latin America averaging the highest at  $\bar{x} = 3210$  t shrimp annually. Production intensities were predictably higher in Asia than Latin America, but certified farms in Asia on average had the highest production intensity of all groups. The FCRs were on average the highest in ASC certified farms in Latin America ( $\bar{x} = 1.80$ ) and were significantly different from the non-certified farms in Latin America, while non-ASC farms were not significantly different from farms in Asia. Water exchange as a percentage of daily pond volume was significantly lower at farms in Asia that were certified than uncertified farms ( $\bar{x} = 0.324$  vs.  $\bar{x} = 6.37$ , respectively), while there were not statistical differences in the water exchange rates of Latin American farms that were certified vs. uncertified. Both Asian and Latin American farms that were certified used less energy than their uncertified counterparts, although the difference was not significant in Latin America (see Fig. 2e).

There were a few differences in chemical use in certified and non-certified farms in Asia and in Latin America (see Table 4). There was a

**Table 1**  
Total Production and Land Cover of ASC farms and total production and land cover by country.

Country	Production (t shrimp)	ASC Production (t shrimp)	% Certified	Total Land Area (ha) <sup>1</sup>	ASC Farm Land (ha)	% Certified
China	1,760,341	2917	0.17	635,710	2177	0.34
Ecuador	510,000	98,829	19.38	216611 <sup>3</sup>	22,439	10.36
Guatemala	17,273	4479	25.93	1560	342	21.92
Honduras	31,500	29,791	94.57	23,560	11,554	49.04
India	622,000	17,531	2.82	183,300	1695	0.92
Indonesia	708,680	173	0.02	210,600	86	0.04
Mexico	157,934	5142	3.26	92,880	1852	1.99
Nicaragua	29,458	3381	11.48	19,992	1458	7.29
Panama	6409	820	12.79	14,035	800	5.70
Thailand	3,472,258	11,642	0.34	51,255.2	461	0.90
Venezuela	24,500	14,842	60.58	6120	5378	87.88
Vietnam	475,000	16,195	3.41	1,015,160	2094	0.21
Global	4966241 <sup>2</sup>	205,742	4.14	3,154,043	50,336	1.60

<sup>1</sup> Pond area from Boyd and McNevin (2018) was corrected with a Land:Water ratio (LWR) from Jescovitch et al. (2016) to obtain a farm area estimate.

<sup>2</sup> Production totals for the countries listed and the total global production were obtained from FAO's fishstat database.

<sup>3</sup> This value is updated from Boyd et al. (2021).

**Table 2**  
A summary of the production characteristics for farms that are ASC certified. The mean for each country is presented. Where NA is found, the data was not available from the audits for that country.

Variables	Latin America													
	Asia			Latin America										
Country (n)	China (3)	India (36)	Indonesia (3)	Thailand (7)	Vietnam (25)	Overall Average (74)	Ecuador (27)	Guatemala (1)	Honduras (12)	Mexico (1)	Nicaragua (1)	Panama (1)	Venezuela (6)	Overall Average (49)
<b>Farm Characteristics</b>														
Total Area/Audit	725.7	46.0	28.7	65.8	83.8	87.5	831.1	341.5	962.9	1852.8	1458.5	800.0	896.3	894.4
Pond Area	725.7	31.5	28.7	61.6	72.1	77.3	557.8	113.8	731.2	463.2	729.2	800.0	691.5	615.3
No. Ponds	16.67	48.77	35.00	32.00	78.25	81.89	65.58	36.00	60.80	335.00	41.00	152.00	148.50	81.91
Pond Size	1.35	1.23	0.73	0.98	0.50	0.93	9.16	NA	13.48	9.18	22.17	3.36	3.66	9.88
Water Exchange Rate	0.00	0.07	0.70	2.53	0.05	0.32	7.91	5.90	5.97	13.11	10.00	7.60	4.83	7.16
Production System* (n of Cat. 1,2,3)	(0,2,0)	(0,0,24)	(0,1,0)	(0,0,7)	(1,0,19)	(1,3,50)	(0,25,1)	(0,1,0)	(0,12,0)	(0,1,0)	(0,1,0)	(0,1,1)	(0,6,0)	(0,47,1)
<b>Production Characteristics</b>														
Annual Production	972	487	58	1663	892	737	3660	4479	2483	5143	3381	820	2474	3210
Production Intensity	18.95	16.55	5.21	29.22	43.63	26.52	4.69	NA	3.09	NA	3.72	1.61	3.69	3.79
Survival	54.8	85.6	79.1	78.1	80.0	81.4	60.4	66.6	56.9	56.0	60.1	35.0	58.4	58.7
FFER	0.59	0.45	0.81	0.00	0.27	0.37	0.73	NA	0.28	NA	0.20	0.52	0.26	0.54
FCR	0.80	1.30	1.28	1.28	1.18	1.24	1.69	1.61	1.95	2.48	1.29	2.49	1.93	1.80
N Load (kg N/t shrimp)	0.9	18.5	0.1	15.3	12.8	14.81	10.1	NA	18.2	1.4	NA	0.0	8.7	11.94
P Load (kg P/t shrimp)	0.07	2.54	0.05	1.63	1.92	2.13	0.41	NA	2.10	1.11	2.66	0.00	1.79	1.19
Energy Use	0.46	16.35	4.07	20.73	41.53	24.25	20.24	15.07	19.14	12.03	2.08	27.99	35.32	20.73

\* From Standard 5.1.3, the three categories describe the type of production system used on the farms. Category 1 = non aerated, non-fed, Category 2 = fed, but not permanently aerated, Category 3 = fed and permanently aerated. The categories do not sum to the number of farms in some cases because not every audit reported the farm category.

significant difference in the rate at which farms reported the use of fertilizer ( $X^2 = 12.85, df = 1, p = 0.0003$ ), Zeolite ( $X^2 = 7.79, df = 1, p = 0.005$ ), and Probiotics ( $X^2 = 13.73, df = 1, p = 0.0002$ ) in Asia farms. In all three cases, the non-ASC farms had a higher rate of reporting chemical use for these chemicals. In Latin America, there was a significant difference in the rate of reporting the use of agricultural limestone ( $X^2 = 6.65, df = 1, p = 0.001$ ), burnt or hydrated lime ( $X^2 = 16.171, df = 1, p \leq 0.0001$ ), carbohydrates ( $X^2 = 49.87, df = 1, p \leq 0.0001$ ), zeolite ( $X^2 = 12.36, df = 1, p = 0.0004$ ), piscicides ( $X^2 = 6.22, df = 1, p = 0.013$ ), and disinfectants ( $X^2 = 34.49, df = 1, p \leq 0.0001$ ). In all cases except disinfectants, ASC farms reported using these chemicals at a lower proportion than their non-certified counterparts.

#### 4. Discussion

Shrimp production is not likely to decrease in the near future, as shrimp production and aquaculture in general is one of the fastest growing food production systems globally (FAO, 2018). Because of past criticisms and increased consumer awareness in the developed world about the environmental impact of their food choices, there is a growing demand for sustainable seafood products (Boyd and McNevin, 2015). One markets-based solution that has become prominent, especially in seafood, is eco-labeling certification. The ASC's shrimp standard, developed through a multi-stakeholder process, is meant to be at the leading front of certifications in the aquaculture sector. Here, we examined the ways in which ASC certified farms differ from their non-certified farms in two areas of the world, Asia and Latin America. This study is not meant to be a criticism of the ASC or certification in general. On the contrary, the findings of this study should serve to strengthen the ASC shrimp standard.

One of the most apparent conclusions from this data is that there are truly two different predominant styles of shrimp farming that have been able to obtain certification. For the most part in Asia, the farms are highly intensive and with small ponds and a comparably small overall area when compared to ASC farms elsewhere, while the farms in Latin America are large and semi-intensive (for the sake of this study, semi-intensive will mean fed but not permanently aerated farms). Even though the average Asian ASC farm is an order of magnitude smaller than the average ASC farm in Latin America, they are still quite large compared to the non-certified farms that were surveyed Boyd et al., (2018) and Boyd et al., (2017).

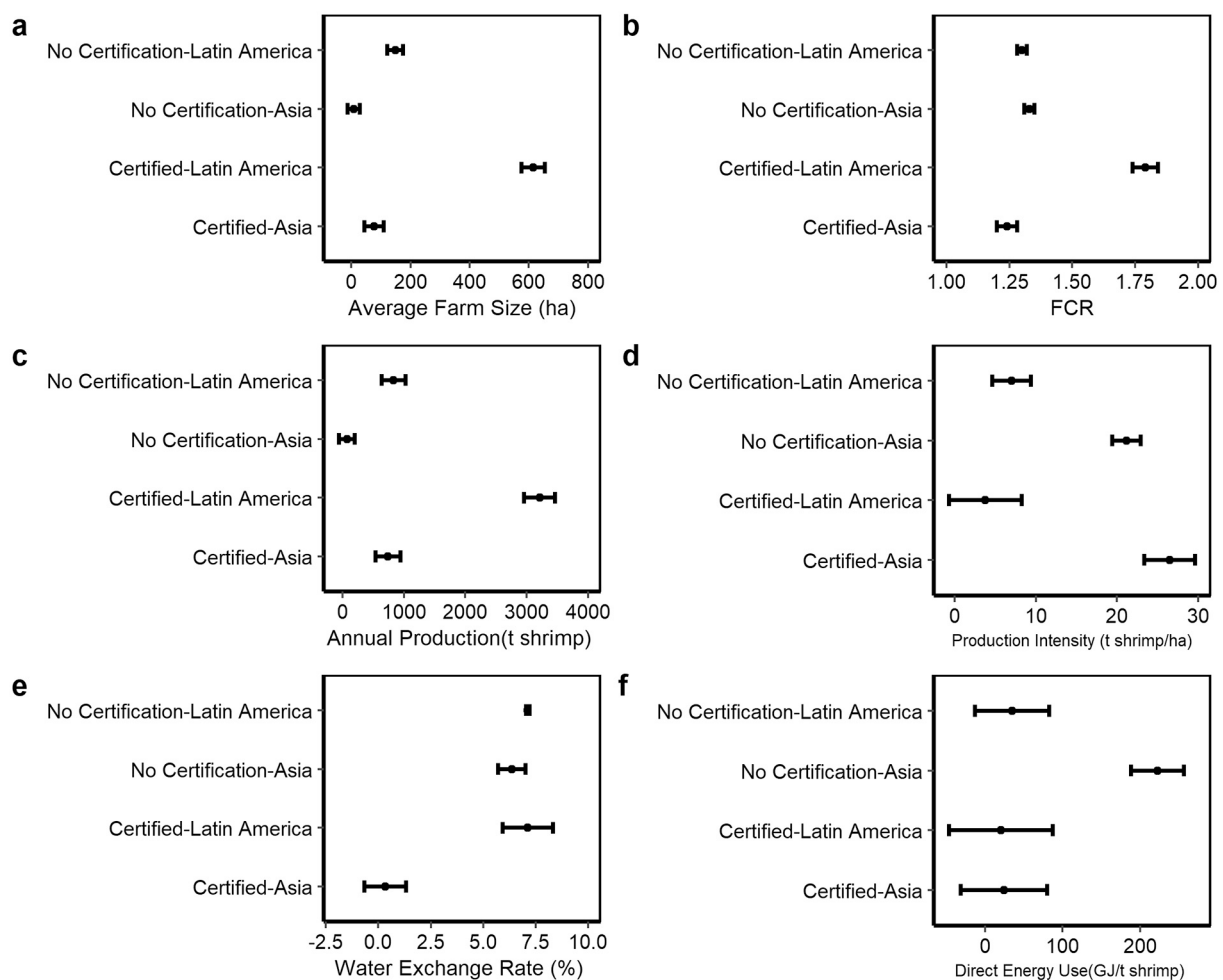
The data revealed here in this study shows how difficult it has been for the ASC shrimp standard to capture a meaningful share of the global shrimp market. In the ~5 years since its conception, approximately 4% of global WLS production is under ASC certification. This has not changed appreciably in the last 2–3 years (authors unpublished data) and is potentially indicative of a scenario where all the farms that can achieve and afford certification already are certified for the ASC. Additionally, the market forces from the retailer/consumer side cannot be ignored as a potential factor in the limits on farms attempting to be certified. Thus, it is likely that the combination of certifiable farms and the market demand are limiting certification.

Based on the size of the farms that are being certified, it is clear that the farms that are able to obtain certification are only those that are either large enough or are producing enough volume in smaller highly intensive farms to absorb the costs of certification, which is understood to be substantial (*sensu Samerwong et al., 2018*). This creates a paradoxical problem for the ASC, that is in order to broaden the market share of the standard and therefore it's potential impact, the standard would likely have to be altered in order to be obtainable for a larger number of farms. ASC has made attempts to address the issue of access to the standard by creating a multi-site and group certification, which allows for more than one farm to be certified at once. Several certifications in this study were multi-site (roughly 25%), so this does seem to be a path to certification for clusters of smaller farms. At least some of these multi-site certifications belong to producer associations, which appear to be

**Table 3**

A comparison of production metrics for ASC and non-ASC farms in Asia and Latin America. The means of each are presented  $\pm$  standard errors. Letters accompanying the mean represent group membership based on post hoc tests on ranks. *P* values for the factors Certification and Region are presented from the corresponding two-way ANOVA (or non-parametric equivalent) for each variable.

Group	Average Farm Size (ha)	Annual Production (t shrimp)	Production Intensity (t/ha pond/yr)	FCR	Water Exchange (%)	Direct Energy Use (GJ/t shrimp)
ASC Asia Farms	77.33 <sup>b</sup> $\pm$ 32.34	740 <sup>b</sup> $\pm$ 203	26.52 <sup>b</sup> $\pm$ 3.12	1.24 <sup>a</sup> $\pm$ 0.04	0.324 <sup>a</sup> $\pm$ 0.989	24.25 <sup>a</sup> $\pm$ 55.67
Non-ASC Asia Farms	7.65 <sup>a</sup> $\pm$ 20.51	70 <sup>a</sup> $\pm$ 131	21.17 <sup>b</sup> $\pm$ 1.76	1.33 <sup>a</sup> $\pm$ 0.02	6.37 <sup>b</sup> $\pm$ 0.660	222.42 <sup>b</sup> $\pm$ 34.31
ASC Latin America Farms	615.25 <sup>d</sup> $\pm$ 39.60	3210 <sup>c</sup> $\pm$ 250	3.79 <sup>a</sup> $\pm$ 4.45	1.80 <sup>b</sup> $\pm$ 0.05	7.116 <sup>c</sup> $\pm$ 1.200	20.74 <sup>a</sup> $\pm$ 66.97
Non-ASC Latin America Farms	149.06 <sup>c</sup> $\pm$ 26.48	829 <sup>b</sup> $\pm$ 194	7.02 <sup>a</sup> $\pm$ 2.40	1.30 <sup>a</sup> $\pm$ 0.02	7.123 <sup>c</sup> $\pm$ 0.0857	34.68 <sup>a</sup> $\pm$ 47.86
Anova (p value)						
Certification	< 0.0001	< 0.0001	0.0297	0.0001	0.348	< 0.0001
Region	< 0.0001	< 0.0001	<0.0001	< 0.0001	< 0.0001	< 0.0001
Interaction	< 0.0001	< 0.0001	0.0035	< 0.0001	0.257	0.0019



**Fig. 2.** Mean ( $\pm$  Std. dev.) values for groups of farms classified by region (Latin America vs. Asia) and certification Status (ASC vs not certified). The variables included are: a). Average Farm Size, b). FCR, c). Annual Farm Production, d). Production Intensity, e). Water Exchange Rate, and f). Direct Energy Use.

consortia of farmers in a local geography. This survey shows that generally large farms achieve certification relative to the farms in their respective area, but that the pathway for smaller farms to achieve certification are available enough that some have chosen to do so as part of collectives.

The ASC standard has rather strict limits on amounts of phosphorus and nitrogen that may be discharged per tonne of shrimp harvested (3.9 kg P/t shrimp and 25.4 kg N/t shrimp, respectively). While compliance with these limits requires better management, these limits do not assure water quality protection in receiving water bodies. The limits do not

restrict a farm from increasing production, and as a result, discharging greater total loads of nitrogen and phosphorus into its receiving water body. However, the important fact is that unless the assimilation capacity of the receiving water body is known, a farm can comply with the ASC nitrogen and phosphorus standards but release enough nitrogen and phosphorus to initiate or exacerbate eutrophication. Moreover, there often are other anthropogenic sources of nitrogen and phosphorus to water bodies into which ASC certified farms discharge (Liu et al., 2012; Wilbers et al., 2014; Li and Bush, 2015). The main benefit of the ASC nitrogen and phosphorus load limits is in discouraging practices

**Table 4**

Amendment use on ASC farms in Asia and Latin America as well as non-ASC certified farms. The percentage of farms that use a particular amendment out of the farms reporting amendments is presented. n = the total number of farms reporting amendment use. P values represent the result of a Chi-square test of independence for the use of chemicals by certified vs. non-certified farms in each region.

Amendments	Asia			Latin America		
	ASC (n = 27)	Non- ASC (n = 111)	p value	ASC (n = 29)	Non- ASC (n = 89)	p value
Agricultural limestone	37.0	53.0	0.141	48.3	75.5	0.010
Burnt or hydrated lime	44.4	35.8	0.616	41.3	81.1	< 0.0001
Fertilization	25.9	63.6	0.0003	75.9	87.1	0.225
Carbohydrate Source	0.0	9.9	0.170	6.9	80.2	< 0.0001
Hydrogen peroxide for emergency oxygenation	3.7	2.0	0.999	20.7	30.7	0.429
Zeolite	3.7	31.3	0.005	3.4	40.5	0.0004
Probiotics	37.0	73.5	0.0002	27.6	33.7	0.719
Piscicides	3.7	10.0	0.470	3.4	27.7	0.013
Therapeutants	0.0	10.0	0.170	17.2	37.6	0.072
Disinfectants	77.8	58.3	0.070	58.6	7.9	< 0.0001
Vitamins	7.4	20.5	0.158	3.4	4.0	0.999

that result in large amounts of nitrogen and phosphorus in farm effluents.

The FCR and by extension type and amount of feed used by a farm largely determines its environmental impact, as feed management plays a role in the amount of embodied resources tied up in production in the farm (Chatvijitkul et al., 2017), the water quality outcomes (Jescovitch et al., 2018), the impacts on wild fish, and the health of shrimp in ponds (Tacon et al., 2013). The ASC farms in Asia had a lower FFER than ASC farms in Latin America, largely as a result to many farms claiming an FFER of zero because fisheries or aquaculture by-products as the source of fishmeal in the feeds. It is important to note that shrimp do not explicitly need fishmeal in their diets (Amaya et al., 2007), and that the percentage of fishmeal inclusion in shrimp feeds have continually fallen, and farm level FCRs have shown improvement through time (Boyd and McNevin, 2015). The worst performing group in this study was the ASC-certified farms in Latin America, and the best performing group was the ASC certified farms in Asia. This continues to drive home the differences in the ASC farms in Asia, and the ASC farms in Latin America. Indeed, there were several ASC farms in Latin America that reported FCRs greater than 2, while there were no farms in Asia that reported and FCR over 2. It is likely that the large size of the ponds in Latin America, indicative to the production systems in this region, limit the ability to manage feed inputs and production. Large ponds are more difficult to manage intensively compared to relatively small ponds (Boyd and Tucker, 2012). In future revisions of the ASC shrimp standards, stricter requirements beyond simply reporting that the calculations were performed correctly for specifically the FCR, protein retention efficiency, and the energy use could strengthen the standard and add to the validity of the claims-making about sustainability of ASC Farms.

Direct energy use is an important measure, as it relates to the use of aeration and pumping on a farm, which are key management practices that can determine the environmental impacts of the farm. ASC farms were better on average than their non-certified peers in both Asia and Latin America, which is encouraging for an eco-label. From the reporting in the standard, it is difficult to tell what is creating this difference, as the pumping and aeration hours are not reported, but it likely tied at least in part to the lower water exchange rate seen in ASC farms in Asia, and the lack of aeration used at ASC farms in Latin America, which did not show

differences in water exchange rates compared to non-certified farms.

The uses of chemicals were generally similar between ASC and non-ASC farms in the same region, with the noted exceptions in the results. When significant differences did arise, it was because that non-certified farms tended to be more likely to use a particular chemical in all cases except for disinfectants in Latin America where ASC farms were more likely to report its use. Chlorination with bleach (NaOCl) and high test hypochlorite [Ca(OCl)<sub>2</sub>] were by far the most common method of chlorination. Disinfection of ponds also eradicates wild fish, so the use of piscicides such as rotenone and saponins was not common in Asia. However, in Latin America, 27.7% of non-ASC farms applied piscicides. These farms did not apply disinfectants generally, and some farms did not use disinfectants or piscicides. The main therapeutants applied were organic acids such as lactic or ascorbic acid which are used to prevent *Vibrio* infections in shrimp (Mine and Boopathy, 2011). None of the ASC farms in Asia used therapeutants, and therapeutant use in Latin America was more common at non-ASC farms. The greatest use of vitamins at non-ASC farms in Asia, and Vitamin C was the common one applied. The ASC audits online do not include treatment rates for pond amendments. However, usual treatment rates are available for farms in India, Thailand, and Vietnam (Boyd et al., 2017; Boyd et al., 2018).

This study is somewhat limited in scope for a few reasons. While the ASC certification is lengthy and requires dozens of pieces of information, the required reporting is not clearly defined in some cases. For example, several audits lack information that should be explicitly required, such as the size of the farms, or the number and size of the ponds. The ASC audits stand to become more transparent with reporting requirements outlined for third party auditors, so that audit reports are more standardized and coherent. Additionally, while several farms listed the amendments used in Standard 7, not one audit listed the rates of the amendments used. This would be more complete for comparison purposes between ASC and non-ASC certified farms. Additionally, the surveys used here as non-certified counterparts to ASC did not capture survival explicitly (Boyd et al., 2017; Boyd et al., 2018; Boyd et al., 2021), so it is difficult to understand if the survival rates at ASC farms are typical or higher than their non-certified counterparts. The most critical pieces of information missing from several of the audits that should be specified to be explicitly included are the actual production of the farm for the most recent complete year, the number of production ponds (and nursery and hatchery ponds separately), the different water surface areas such as the production ponds, canals, and reservoirs if any are present, and the total area of the property and the area dedicated to shrimp farming in the cases where not all of the property is utilized.

## 5. Conclusions

The authors want to emphasize that this report is not a condemnation of the ASC shrimp standard. Indeed, this analysis was only possible because of the transparency of the ASC, which reports its audits publicly, unlike other standards such as the Global Aquaculture Alliance's Best Aquaculture Practice (BAP) standard which does not. It is difficult to know how the farms certified to ASC standard would compare to the farms certified to the BAP standard on a benchmarking exercise because of this, although it should be noted that there are farms in many countries that are certified to both standards. Broadly, there are some conclusions to be made about the ASC certified farms. The ASC appears to have captured the high end of the market in terms of farm size, suggesting that large, in many cases corporate, farms are the farms that are able to obtain certification. There appears to be a dichotomy between Latin America and Asia in terms of farm style and management, although this was relatively well known. Perhaps more importantly, ASC farms do not appear to be drastically different from non-certified farms from technical aspects, and outside of energy use, they are possibly middling performers (e.g., FCR, water exchange).

Finally, while technical efficiency is an important aspect of sustainability and was the focus of this study, this study does not capture the

entirety of what the ASC certification is meant to assess, including other important aspects of responsible farming such as fair labor practices, supply chain traceability, community engagement, previous land use at the farm site, and local regulation compliance. Moving forward, aligning the standards related to technical proficiency (and going beyond the bare minimum requirement of simply reporting that the calculation was performed in many cases) with what is the current best approach management at the farm level will improve the ASC shrimp standard. Several key indicators for farm management, such as energy use and eFCR, do not have a requirement that must be obtained beyond calculation. Additionally, the standard should explicitly require the farm to outline the total size of the farm, number of ponds, and water surface area, which are critical to understanding farm management. Periodic comparisons of ASC certification data to industry surveys will strengthen the claims made by the ASC, mainly that they are a leader in environmental stewardship in aquaculture.

## Acknowledgements

This study was funded by an initiative from the Gordon and Betty Moore Foundation.

## References

- Amaya, E., Davis, D.A., Rouse, D.B., 2007. Alternative diets for the Pacific white shrimp *Litopenaeus vannamei*. *Aquaculture* 262, 419–425.
- Aquaculture Stewardship Council, 2014. ASC Shrimp Standard. The Netherlands, Utrecht, p. 144.
- Bailey, C., 1988. The social consequence of tropical shrimp mariculture development. *Ocean Shoreline Manag.* 11, 31–44.
- Boyd, C.E., McNeven, A.A., 2015. Aquaculture, Resource Use, and the Environment. John Wiley and Sons, Hoboken, New Jersey.
- Boyd, C.E., McNeven, A.A., 2018. Land Use in Shrimp Aquaculture. *World Aquaculture Society, World Aquaculture Magazine*.
- Boyd, C.E., Tucker, C.S., 2012. Pond aquaculture water quality management. Springer Science and Business Media.
- Boyd, C.E., McNeven, A.A., Racine, P., Tinh, H.Q., Minh, H.N., Viriyatum, R., Paungkaew, D., Engle, C., 2017. Resource Use Assessment of Shrimp, *Litopenaeus vannamei* and *Penaeus monodon*, Production in Thailand and Vietnam. *J. World Aquacult. Soc.* 48, 201–226.
- Boyd, C.E., McNeven, A.A., Davis, R.P., Godumala, R., Mohan, A.B.C., 2018. Production methods and resource use at *Litopenaeus vannamei* and *Penaeus monodon* farms in India compared with previous findings from Thailand and Vietnam. *J. World Aquacult. Soc.* 49, 551–569.
- Boyd, C.E., Davis, R.P., Gonzalez Wilson, A., Marcillo, F., Brian, S., A., M., 2021. Resource use in whiteleg shrimp *Litopenaeus vannamei* farming in Ecuador. *J. World Aquacult. Soc.* (In press).
- Chamberlain, G.W., 2010. History of Shrimp Farming. In: Alday-Sanz, V. (Ed.), *The Shrimp Book*. Nottingham University Press, Nottingham, United Kingdom, pp. 1–35.
- Chatvijitkul, S., Boyd, C.E., Davis, D.A., McNeven, A.A., 2017. Embodied Resources in Fish and Shrimp Feeds. *J. World Aquacult. Soc.* 48, 7–19.
- Clay, J., 1996. Market potential for redressing the environmental impact of wild-captured and pond-produced shrimp. *World Wildlife Fund, Washington D.C., USA*.
- Clay, J.W., 2008. The role of better management practices in environmental management. In: Tucker, C.S., Hargreaves, J.A. (Eds.), *Environmental Best Management Practices for Aquaculture*. Blackwell Publishing, Oxford, UK, pp. 55–72.
- Del Giudice, T., Stranieri, S., Caracciolo, F., Ricci, E.C., Cembalo, L., Banterle, A., Cicia, G., 2018. Corporate Social Responsibility certifications influence consumer preferences and seafood market price. *J. Clean. Prod.* 178, 526–533.
- Edwards, P., Zhang, W.B., Belton, B., Little, D.C., 2019. Misunderstandings, myths and mantras in aquaculture: Its contribution to world food supplies has been systematically over reported. *Mar. Policy* 106.
- FAO, 2009. How to feed the world in 2050, Insights from an expert meeting at FAO. FAO.
- FAO, 2018. The State of World Fisheries and Aquaculture 2018 - Meeting the Sustainable Development Goals. FAO, Rome, Italy, p. 227.
- FAO (Ed.), 2019. Fishery and Aquaculture Statistics (FishstatJ). In FAO editor. *Global Capture Production*, Rome, Italy.
- Giri, C., Long, J., Abbas, S., Murali, R.M., Qamer, F.M., Pengra, B., Thau, D., 2015. Distribution and dynamics of mangrove forests of South Asia. *J. Environ. Manag.* 148, 101–111.
- Hodal, K., Kelly, C., Lawrence, F., 2014. Revealed: Asian Slave Labour Producing Prawns for Supermarkets in US, UK. *Guardian News*.
- Holmstrom, K., Graslund, S., Wahlstrom, A., Pongshompo, S., Bengtsson, B.E., Kautsky, N., 2003. Antibiotic use in shrimp farming and implications for environmental impacts and human health. *Int. J. Food Sci. Technol.* 38, 255–266.
- Jescovitch, L.N., Chaney, P.L., Boyd, C.E., 2016. A preliminary assessment of land-to-water surface area ratios (LWR) for sustainable land use in aquaculture. *Papers Appl. Geograp.* 2, 178–188.
- Jescovitch, L.N., Ullman, C., Rhodes, M., Davis, D.A., 2018. Effects of different feed management treatments on water quality for Pacific white shrimp *Litopenaeus vannamei*. *Aquac. Res.* 49, 526–531.
- Jones, A.B., O'Donohue, M.J., Udy, J., Dennison, W.C., 2001. Assessing ecological impacts of shrimp and sewage effluent: Biological indicators with standard water quality analyses. *Estuar. Coast. Shelf Sci.* 52, 91–109.
- Li, S., Bush, R.T., 2015. Rising flux of nutrients (C, N, P and Si) in the lower Mekong River. *J. Hydrol.* 530, 447–461.
- Liu, C., Kroeze, C., Hoekstra, A.Y., Gerbens-Leenes, W., 2012. Past and future trends in grey water footprints of anthropogenic nitrogen and phosphorus inputs to major world rivers. *Ecol. Indic.* 18, 42–49.
- Mine, S., Boopathy, R., 2011. Effect of organic acids on shrimp pathogen, vibrio harveyi. *Curr. Microbiol.* 63, 1–7.
- Naylor, R.L., Goldburg, R.J., Mooney, H., Beveridge, M., Clay, J., Folke, C., Kautsky, N., Lubchenco, J., Primavera, J., Williams, M., 1998. Ecology - Nature's subsidies to shrimp and salmon farming. *Science* 282, 883–884.
- Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., Troell, M., 2000. Effect of aquaculture on world fish supplies. *Nature* 405, 1017–1024.
- Norman, G., Streiner, D., 2014. *Bisostatistics: The Bare Essentials*. People's Medical Publishing House USA, Shelton, Connecticut USA.
- Primavera, J.H., 2006. Overcoming the impacts of aquaculture on the coastal zone. *Ocean Coast. Manag.* 49, 531–545.
- R Core Team, 2019. R: A language and environment for statistical computing. Austria. R Foundation for Statistical Computing, Vienna.
- Roheim, C.A., Asche, F., Santos, J.I., 2011. The elusive price premium for ecolabelled products: evidence from Seafood in the UK Market. *J. Agric. Econ.* 62, 655–668.
- Samerwong, P., Bush, S.R., Oosterveer, P., 2018. Implications of multiple national certification standards for Thai shrimp aquaculture. *Aquaculture* 493, 319–327.
- Sansanayuth, P., Phadungchep, A., Ngammontha, S., Ngdngam, S., Sukasem, P., Hoshino, H., Ttabucanon, M.S., 1996. Shrimp pond effluent: Pollution problems and treatment by constructed wetlands. *Water Sci. Technol.* 34, 93–98.
- Tacon, A.G.J., Jory, D., Nunes, A., 2013. Shrimp feed management: issues and perspectives. In: *On-Farm Feeding and Feed Management in Aquaculture*, 583, pp. 481–488.
- UN, 2020. UN Comtrade Database. The United Nations.
- Wilbers, G.-J., Becker, M., La Thi, N., Sebesvari, Z., Renaud, F.G., 2014. Spatial and temporal variability of surface water pollution in the Mekong Delta, Vietnam. *Sci. Total Environ.* 485, 653–665.
- Wobbrock, J.O., Findlater, L., Gergle, D., Higgins, J.J., Acm, 2011. The Aligned Rank Transform for Nonparametric Factorial Analyses Using Only ANOVA Procedures. In: 29th Annual Chi Conference on Human Factors in Computing Systems, pp. 143–146.
- Zhang, W.B., Murray, F.J., Liu, L.P., Little, D.C., 2017. A comparative analysis of four internationally traded farmed seafood commodities in China: domestic and international markets as key drivers. *Rev. Aquac.* 9, 157–178.