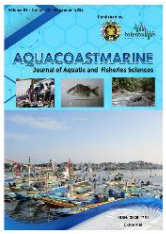
talenta PUBLISHER

AQUACOASTMARINE
Journal of Aquatic and Fisheries Sciences
Journal homepage: https://talenta.usu.ac.id/aquacoastmarine



# Aggression and Size Heterogeneity Indicate Cannibalism Risk in Barramundi (*Lates calcarifer*) Juveniles

# Agresivitas dan Heterogenitas Ukuran Sebagai Indikator Risiko Kanibalisme Pada Benih Kakap Putih (*Lates calcarifer*)

Indra Lesmana[*1 3], Irwan Effendi[2], Indra Suharman[3], Iskandar Putra[3], Manta Prayanti[3], Kristina Kristina[3]

[1]*Doctoral Program in Marine Sciences, Graduate School Universitas Riau, Pekanbaru, 28293 Indonesia*
[2]*Department of Marine Science, Faculty of Fisheries and Marine, Universitas Riau, Pekanbaru, 28293 Indonesia*
[3]*Department of Aquaculture, Faculty of Fisheries and Marine Universitas Riau, Pekanbaru, 28293 Indonesia*
[*]Corresponding Author: indra.lesmana@lecturer.unri.ac.id

**ARTICLE INFO**

**Article history:**
Received 20 May 2026
Revised 20 October 2026
Accepted 01 November 2026
Available online 16 November 2026

E-ISSN: 2829-1751

**How to cite:**
Lesmana, I., Effendi, I., Suharman, I., Putra, I., Prayanti, M., Kristina, K. (2026). Aggression and Size Heterogeneity Indicate Cannibalism Risk in Barramundi (Lates calcarifer) Juveniles *AQUACOASTMARINE: J.Aquat.Fish.Sci*,, 5(2), 241-253

**ABSTRACT**

Cannibalism in juvenile barramundi (*Lates calcarifer*) nurseries involves aggressive interactions, injury, fish disappearance, and changes in size distribution. This study examined aggression and size heterogeneity as candidate indicators of cannibalism-associated risk. Juveniles were reared for 30 days at 0.5 or 2 fish $L^{-1}$ in small-, large-, and mixed-size groups (three replicate containers per combination). Aggressive acts, injury and six-hourly fish inventories, body-weight variation, potential cannibals, and reported correlations were evaluated. The highest aggressive behaviour index occurred at high density with mixed sizes (18.52 ± 4.68 per 30-min session), alongside frequent chasing, biting, injury, and missing fish. Across treatments, 81 injured-fish observations, 137 missing individuals suspected as cannibalism, and seven Type II inventory events were reported. The greatest final weight coefficient of variation was 60.49% in the low-density mixed-size group. Aggression was positively associated with recorded cannibalism (r = 0.702), whereas suspected total cannibalism was inversely correlated with survival (r = −0.912). As missing-fish and survival measures are partly mathematically coupled, these associations do not establish causality or validated prediction. Joint behavioural and size monitoring may assist nursery surveillance, but requires prospective validation.

**Keyword:** aggressive behavior; barramundi juvenile; cannibalism risk; nursery management; size heterogeneity

**ABSTRAK**

Kanibalisme pada pendederan benih kakap putih (*Lates calcarifer*) berkaitan dengan agresivitas, cedera, kehilangan ikan, dan perubahan sebaran ukuran. Penelitian ini mengevaluasi agresivitas dan heterogenitas ukuran sebagai kandidat indikator risiko yang berhubungan dengan kanibalisme. Benih dipelihara 30 hari pada dua padat tebar (0,5 dan 2 ekor $L^{-1}$) serta tiga kategori ukuran (kecil, besar, campuran), masing-masing tiga ulangan. Pengamatan mencakup perilaku agresif, inventarisasi ikan setiap enam jam, cedera, variasi bobot, dan korelasi antarvariabel. Indeks agresivitas tertinggi terdapat pada padat tebar tinggi dengan ukuran campuran, yaitu 18,52 ± 4,68 per sesi 30 menit, bersamaan dengan banyaknya kejadian mengejar, menggigit, cedera, dan ikan hilang. Seluruh

This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International.
10.32734/jafs.v5i2.25679

perlakuan mencatat 81 pengamatan ikan cedera, 137 ikan hilang yang diduga mengalami kanibalisme, dan tujuh kejadian tipe II berdasarkan inventarisasi. Koefisien variasi bobot akhir tertinggi adalah 60,49% pada kelompok ukuran campuran dengan padat tebar rendah. Indeks agresivitas berkorelasi positif dengan kanibalisme tercatat (r = 0,702), sedangkan dugaan total kanibalisme berkorelasi negatif dengan sintasan (r = −0,912). Karena variabel ikan hilang dan sintasan sebagian saling terkait secara matematis, hasil ini tidak membuktikan hubungan sebab-akibat maupun kemampuan prediksi yang tervalidasi. Pemantauan perilaku dan ukuran secara terpadu berpotensi mendukung pengelolaan pendederan, tetapi memerlukan validasi prospektif.

**Kata Kunci:** agresivitas; benih kakap putih; heterogenitas ukuran; kanibalisme; manajemen pendederan

## 1. Introduction

Barramundi or Asian seabass (*Lates calcarifer*) is an economically important marine and brackish-water aquaculture species with considerable potential for hatchery-based juvenile production and intensive nursery development. Its rapid growth, market value, euryhaline physiology, and adaptability to different culture systems support commercial cultivation. Nevertheless, nursery performance depends on the availability of healthy, size-uniform juveniles and consistently high survival. Size dispersion and cannibalism during seed production are recognised constraints under hatchery conditions, including those described in Indonesian barramundi production (Lesmana et al., 2025).

A major constraint in juvenile barramundi nurseries is intracohort cannibalism, which can cause stock loss, injury, altered size distributions, and reduced production efficiency. Cannibalism refers to consumption of a conspecific and can range from partial attacks to complete ingestion. Its occurrence varies with developmental stage, predator–prey size compatibility, and environmental conditions (Baras & Jobling, 2002; Duk et al., 2017; Pereira et al., 2017). Consequently, cannibalism is not adequately characterised by end-point mortality alone: both behavioural interactions and the changing size structure of the cohort warrant observation.

Among predatory juveniles, cannibalism has been associated with feeding competition, dominant–subordinate interactions, body-size dispersion, and mouth-gape constraints (Baras & Jobling, 2002; Kestemont et al., 2003). Chasing and attacking may precede biting, injury, or predation; however, aggression is not synonymous with confirmed cannibalism. Unequal access to feed can also promote growth depensation, potentially favouring larger, faster-growing individuals. Observational studies of social fish behaviour indicate that aggression must be defined using clear operational criteria and distinguished from accompanying subordinate or feeding responses (Filby et al., 2010).

Stocking density can alter encounter frequency, social competition, and access to food and space. Published barramundi experiments have shown effects of stocking density and tank conditions on growth, survival, and cannibalism, including favourable outcomes at a low density of 0.5 fish $L^{-1}$ in one nursery system (Khan et al., 2022). A separate study demonstrated that higher feeding frequency and lower density delayed size dispersion and cannibalism in juvenile barramundi (Ribeiro et al., 2015). Nevertheless, density effects should not be assumed to be universal because fish size, feeding level, enclosure design, and species can modify the direction and magnitude of behavioural responses.

Size heterogeneity is another relevant factor because mixed-size fish provide potential predator–prey combinations within the same cohort. Greater differences in body length, body depth, and mouth dimensions can increase the likelihood that larger fish capture smaller conspecifics. For barramundi, size-dependent ingestion has been examined experimentally and shows that predator–prey size compatibility is a central mechanism, rather than body mass alone (Ribeiro & Qin, 2013). Other Asian seabass studies also link size dispersion, feeding conditions, and juvenile cannibalism (Liu et al., 2017; Pham et al., 2020; Ribeiro et al., 2015). This provides a rationale for comparing uniform and mixed-size groups while distinguishing pre-existing heterogeneity from variation that develops during rearing.

In routine hatchery practice, cannibalism is often described using final survival, numbers of injured fish, or individuals not recovered during stock checks. Such observations are useful but do not invariably identify when predation occurred or prove that every missing fish was consumed. Repeated observations of chasing, attacking, biting, injuries, feeding-site dominance, and body-size dispersion could be practical candidate signals for closer surveillance. Demonstration of true predictive performance, however, requires time-resolved analyses showing that an indicator precedes subsequent loss, rather than merely correlates with loss measured during the same period.

Existing research has addressed stocking density, feeding management, growth, cannibalism, and size

grading in Asian seabass and related predatory fishes (Baras & Jobling, 2002; Kestemont et al., 2003; Khan et al., 2022, 2023; Liu et al., 2017; Pham et al., 2020; Ribeiro et al., 2015). Comparatively less attention has been paid to assessing several behavioural and population-structure measures together in a single barramundi nursery dataset. The scientific contribution pursued here is therefore not the invention of a new universal aggression scale or a proof of causal prediction, but an integrated descriptive assessment of behavioural intensity, observed injuries, suspected disappearance, and size dispersion across contrasting density and size-class combinations.

Accordingly, this study aimed to characterise aggressive interactions and size heterogeneity in barramundi juveniles reared at two stocking densities and three initial size categories; describe their correspondence with documented predation, injury, missing fish, and survival; and identify candidate indicators that could inform practical nursery monitoring. Particular attention was given to distinguishing directly observed events from suspected cannibalism and recognising the limitations of contemporaneous correlation analyses.

## 2. Material and Method

### 2.1. Study site and experimental animals

This study was conducted from February to April 2025 at the barramundi nursery facility of the Marine Aquaculture Development Center, Batam, Riau Islands Province, Indonesia. The experimental fish were barramundi (*Lates calcarifer*) juveniles obtained from the same hatchery batch to minimize differences in origin and early rearing history. Before the experiment, fish were acclimatized to the nursery condition and selected based on active swimming behavior, normal morphology, absence of visible injury, and good feeding response.

### 2.2. Experimental design

This article analyses a subset of the first-stage nursery experiment focused on behaviour, injury, size heterogeneity, and cannibalism-related loss. A two-factor factorial arrangement combined two stocking densities (0.5 and 2 fish $L^{-1}$) and three initial size categories (small, large, and mixed), with three replicate containers per combination (18 experimental units). At a working water volume of 20 L, these densities corresponded to initial allocations of 10 and 40 fish per container, respectively. The density contrast was chosen to examine low- versus high-contact nursery conditions, with the lower density informed by barramundi nursery literature (Khan et al., 2022; Ribeiro et al., 2015); the high density represented a higher-contact experimental condition, not a recommended commercial stocking rate. Small and large juveniles were defined in the submitted experimental protocol as total length ≤3 cm and >3 cm, respectively; mixed-size containers held both categories. These cut-offs were operational group definitions rather than experimentally validated cannibalism thresholds, and results should not be extrapolated to every size or facility.

Treatment codes were defined as follows: P1 = 0.5 fish $L^{-1}$, P2 = 2 fish $L^{-1}$, S1 = small juveniles, S2 = large juveniles, and S3 = mixed-size juveniles; therefore, P1S1, P1S2, P1S3, P2S1, P2S2, and P2S3 represented all stocking density and seed-size combinations. The design also created unequal starting numbers of fish across densities. Consequently, event counts per unit and the proportion of fish affected answer different questions: counts describe the operational burden per container, whereas proportions offer an initial-size-adjusted description. Neither adjustment alone removes possible differences in encounter opportunity. The present descriptive analyses retain both scales where appropriate.

Fish were reared for 30 days in plastic containers with a 20-L working water volume and continuous aeration. They received commercial feed containing approximately 45% crude protein three to four times daily to apparent satiation. Uneaten feed and faecal material were removed regularly by siphoning, and water replacement was carried out when necessary. All treatment combinations were managed according to the same general husbandry approach. Because fish number differed by design, between-density comparisons of injury and missing fish should consider the number initially stocked as well as counts per container. The study focused on aggressive interaction, injury, cannibalism-related observations, and size dispersion; growth measurements served to characterise cohort structure.

### 2.3. Behavioral observation and ethogram

Aggressive behaviour was recorded by direct observation, supported by video recording, particularly during feeding and active swimming. Chasing, attacking, biting, avoidance, feeding-area dominance, feeding activity, and visible predation were classified using operational definitions in **Table 1**. This was a study-specific ethogram informed by general fish aggression research (Filby et al., 2010), descriptions of intracohort cannibalism (Baras & Jobling, 2002) (Hecht & Pienaar, 1993), and observations of juvenile barramundi (Ribeiro et al., 2015; Ribeiro & Qin, 2013). It was not copied as a validated numerical ethogram from any

single publication. The behavioural frequency measures in Table 3 refer to 30-min observation sessions; behavioural counts and predation-event totals were retained in their originally reported units.

**Table 1**. Operational ethogram used to describe aggressive and cannibalism-related responses in barramundi juveniles (adapted conceptually from (Baras & Jobling, 2002; Filby et al., 2010; Hecht & Pienaar, 1993; Ribeiro et al., 2015); operational definitions developed for this study).

| Behavioral category | Operational definition | Biological interpretation |
|---|---|---|
| Chasing | One fish actively followed or pursued another fish for a short period | Early aggressive interaction |
| Attacking | One fish made a rapid movement toward another fish | Escalated aggression |
| Biting | One fish contacted or bit another fish, with or without visible injury | Direct aggressive contact |
| Avoidance | Fish moved away rapidly after being approached or attacked | Subordinate or escape response |
| Feeding-area dominance | One or several individuals occupied and controlled the feeding area | Social dominance and feeding competition |
| Feeding activity | Fish actively consumed feed during feeding time | Feeding response and competition level |
| Actual predation | One fish attacked, swallowed, or partially consumed another fish | Confirmed cannibalistic behavior |

For each observation session, the frequency of three directly aggressive acts was recorded and combined into a descriptive aggressive behaviour index (AI). The operational weights used in the reported dataset were 1 for chasing, 2 for attacking, and 3 for biting. These weights rank the escalation of contact severity and reconstruct the AI values in **Table 3**; they were specified for this study and should not be represented as a previously validated standard scale. Avoidance, feeding activity, feeding-area dominance, and predation events were analysed separately to prevent combining responses, social context, and the cannibalism outcome in the same index. The index was calculated as follows:

Aggressive behaviour index (AI), per 30-min session:

$$AI = 1 \times F_{chasing} + 2 \times F_{attacking} + 3 \times F_{biting} \quad \ldots\ldots 1)$$

Here F is the number of observations of the named act within a session. The resulting AI is an internally consistent, ordinally weighted composite of reported aggression frequency, not an absolute physiological measurement of aggressiveness. For example, the P2S3 means (8.17 chasing, 3.21 attacking, and 1.31 biting events per session) yield $AI = 8.17 + 2(3.21) + 3(1.31) = 18.52$. The use of increasing severity weights is conceptually consistent with behavioural escalation described in fish, but the exact weights are investigator-defined (Baras & Jobling, 2002; Filby et al., 2010).

### 2.4. Six-hour observation log of injury and cannibalism risk

Cannibalism-related events were assessed using a six-hourly inventory over the 30-day period, with checks scheduled at 00:00, 06:00, 12:00, and 18:00. For each container, logs distinguished surviving fish, visible injuries, recovered dead fish without evident predation, recovered partially consumed individuals, directly observed or otherwise confirmed complete ingestion, and missing fish. Missing fish were considered suspected cannibalism only when an individual could not be recovered and escape was not evident. Because absence alone cannot establish ingestion, suspected loss was retained as a separate observational category.

Definitions of partial and complete cannibalism followed the general distinctions described in classical fish-cannibalism literature (Baras & Jobling, 2002; Hecht & Pienaar, 1993). Type I denoted incomplete or partial consumption, while Type II referred to complete ingestion of a conspecific. Visible wounds or damaged fins were recorded as injury and were not automatically counted as confirmed Type I consumption. 'Non-cannibalism mortality' designated recovered dead fish with no observed predation or evidence of conspecific consumption; this was an operational field category, not proof of a particular cause of death. A missing fish was treated as suspected, not confirmed, Type II cannibalism. These distinctions reduce, but do not eliminate, misclassification when attacks occur between observations.

The log therefore contributed several non-interchangeable measures: aggressive behavioural events, injured individuals, directly observed predation events, confirmed complete-cannibalism losses, and individuals

absent at stock checks. Table 3 reports direct predation as behavioural-event totals, whereas Table 4 reports Type II as fish-loss counts in the inventory; these should not be assumed to count identical observational units or independent episodes. The available summary records do not establish an event-by-event correspondence. Inferences about the sequence from aggression to loss remain provisional without a formal temporal lead–lag analysis.

### 2.5. Size heterogeneity assessment

Size heterogeneity was evaluated based on individual body weight and total length data collected during the rearing period. Measurements were conducted at the beginning and at scheduled sampling times during the experiment, including the initial, intermediate, and final observation points. Body weight was measured using a digital balance, while total length was measured using a ruler or caliper. Body-size dispersion was expressed as the coefficient of variation (CV) of weight and total length for individual fish sampled within a container. CV is a conventional unit-free descriptive statistic applied to growth heterogeneity in cultured fishes (Kestemont et al., 2003; Ribeiro et al., 2015; Sepúlveda-Quiroz et al., 2024). It was calculated as follows:

$$CV\ (\%) = (\text{standard deviation} / \text{arithmetic mean}) \times 100 \ldots\ldots 2)$$

The mean and standard deviation were calculated for fish measured at the same sampling point within an experimental unit. Larger values indicate greater dispersion relative to the mean, but a change in CV can reflect heterogeneous individual growth, selective survival, or both. The body-weight CV was emphasised because its response to differential feed access and growth depensation may be more pronounced than the corresponding length CV; this is a working interpretation supported by size-heterogeneity research rather than a universal statistical rule (Kestemont et al., 2003; Ribeiro et al., 2015).

### 2.6. Potential cannibal identification

Potential cannibals were screened using the operational criterion reported in the original study: an individual body weight approximately two to three times the contemporaneous container mean. This threshold is a descriptive 'large-individual' screening rule, not a published species-specific physiological cut-off for cannibalism. Research on barramundi instead shows that predation feasibility depends strongly on predator–prey length ratios, gape capacity, and morphology (Ribeiro & Qin, 2013). Thus, weight-based potential-cannibal counts in Table 5 indicate unusually large individuals and should not be equated with verified cannibals or validated prediction thresholds.

The emergence of potential cannibals was therefore evaluated alongside within-container CV, visible aggression, and injuries, rather than being used as stand-alone confirmation of predation. Further validation would require measurements of individual gape, prey body depth or length, documented ingestion events, and time ordering of the proposed indicators (Ribeiro et al., 2015; Ribeiro & Qin, 2013).

### 2.7. Water quality monitoring

Water quality was monitored as a supporting parameter to ensure that behavioral responses and cannibalism risk were not primarily caused by extreme environmental stress. The observed water quality parameters included temperature, pH, dissolved oxygen, salinity, ammonia, and nitrite. Temperature was measured routinely, while pH, dissolved oxygen, salinity, ammonia, and nitrite were measured periodically during the rearing period. Water quality data were interpreted descriptively to verify whether the nursery environment remained within a suitable range for barramundi juveniles.

Monitoring frequency for temperature, pH, dissolved oxygen, salinity, ammonia, and nitrite followed the original facility records. However, the provided summary does not contain the underlying water-quality range or a complete table; therefore, this manuscript does not assert that all variables were statistically identical across treatments or infer the absence of water-quality stress solely from continuous aeration.

### 2.8. Data analysis

Behavioral data, six-hour observation log data, size heterogeneity data, potential cannibal data, cannibalism data, and survival data were tabulated using spreadsheet software. The data were presented as mean ± standard deviation. The main variables analyzed in this article were aggressive behavior index, injured fish, missing fish suspected as cannibalism, type I cannibalism, type II cannibalism, CV of body weight, CV of total length, potential cannibal occurrence, recorded cannibalism, suspected total cannibalism, and survival rate.

Variables were summarised descriptively as mean ± standard deviation for replicate containers, with the container as the experimental unit. The factorial arrangement included density (two levels), initial size class (three levels), and their interaction. The original manuscript reports correlations but does not present a

complete factorial ANOVA table, model diagnostics, or post-hoc results for every outcome. Therefore, the descriptive patterns below are not labelled significant treatment effects unless supported by a reported test. For a confirmatory reanalysis, counts may require rate denominators and models suited to their distribution, and repeated observations within a container must not be treated as independent replicates.

Pearson correlations reported in Table 6 were retained as originally presented. These statistics describe associations among the recorded variables; no raw-data re-estimation is implied in this revision. Associations involving suspected total cannibalism and survival demand particular caution because numbers missing and numbers remaining are components of the same population accounting identity. The variables are thus partly mathematically coupled, so a large negative r alone is not independent confirmation that fish disappearance resulted from cannibalism. Similarly, a correlation between aggression aggregated over rearing and loss aggregated over rearing cannot demonstrate prospective predictive ability or cause–effect direction. Formal early-warning validation would require container-level time series, lagged event analysis, and external replication.

**Table 2**. Main variables used to evaluate early indicators of cannibalism risk in barramundi juveniles.

| Variable group | Variable | Function in this study |
|---|---|---|
| Aggressive behavior | Chasing, attacking, biting, actual predation, aggressive behavior index | Early behavioral indicator |
| Injury and loss | Injured fish, missing fish, type I cannibalism, type II cannibalism | Transition indicator from aggression to cannibalism |
| Size heterogeneity | CV of body weight and CV of total length | Population structure indicator |
| Potential cannibal | Fish with body weight two to three times higher than population mean | Dominant individual indicator |
| Cannibalism response | Recorded cannibalism and suspected total cannibalism | Cannibalism risk outcome |
| Population response | Survival rate | Final biological response |
| Supporting parameter | Water quality | Environmental control variable |

## 3. Result and Discussion

### 3.1. Aggressive behavior profile of barramundi juveniles

Across the six combinations, mean AI ranged from 3.56 ± 1.60 in P1S2 (0.5 fish $L^{-1}$, large juveniles) to 18.52 ± 4.68 in P2S3 (2 fish $L^{-1}$, mixed juveniles), expressed per 30-min observation session. The P2S3 group also had the largest reported counts of chasing (8.17 ± 2.20), attacking (3.21 ± 1.24), and biting (1.31 ± 0.80) per session, together with higher avoidance and feeding-area dominance scores than the other combinations (**Table 3**; **Figure. 1**). These data indicate the most intense observed aggressive interactions in the high-density mixed-size treatment, but the available summary does not establish a statistically significant density-by-size interaction.

**Table 3**. Aggressive behavior profile of barramundi juveniles reared at different stocking densities and seed-size categories.

| Treatment | Chasing | Attacking | Biting | Avoidance | Feeding-area dominance | Feeding activity | Actual predation | Aggressive behavior index |
|---|---|---|---|---|---|---|---|---|
| P1S1 | 2.19 ± 1.07 | 0.65 ± 0.60 | 0.12 ± 0.33 | 1.44 ± 0.82 | 1.54 ± 0.50 | 4.06 ± 0.24 | 3 | 3.85 ± 1.97 |
| P1S2 | 2.10 ± 0.88 | 0.42 ± 0.50 | 0.21 ± 0.41 | 1.42 ± 0.87 | 1.40 ± 0.49 | 4.19 ± 0.39 | 1 | 3.56 ± 1.60 |
| P1S3 | 4.81 ± 1.68 | 1.69 ± 0.80 | 0.62 ± 0.61 | 3.42 ± 1.40 | 2.69 ± 0.55 | 3.50 ± 0.51 | 0 | 10.06 ± 3.44 |
| P2S1 | 5.46 ± 1.65 | 1.90 ± 1.02 | 0.77 ± 0.69 | 3.69 ± 1.55 | 2.67 ± 0.63 | 3.60 ± 0.49 | 4 | 11.56 ± 3.70 |
| P2S2 | 4.33 ± 1.91 | 1.35 ± 0.93 | 0.54 ± 0.65 | 3.35 ± 1.67 | 2.46 ± 0.54 | 3.73 ± 0.45 | 6 | 8.67 ± 3.50 |
| P2S3 | 8.17 ± 2.20 | 3.21 ± 1.24 | 1.31 ± 0.80 | 5.71 ± 1.68 | 4.12 ± 0.76 | 2.83 ± 0.38 | 14 | 18.52 ± 4.68 |

Values for chasing, attacking, biting, avoidance, feeding-area dominance, feeding activity, and AI are mean ± standard deviation per 30-min observation session. Actual predation represents the reported total number of observed behavioural events across the monitoring period and is not a session mean or necessarily the same counting unit as the Type II losses in **Table 4**. AI was computed from chasing, attacking, and biting only, with weights 1, 2, and 3, respectively (**Eq. 1**).

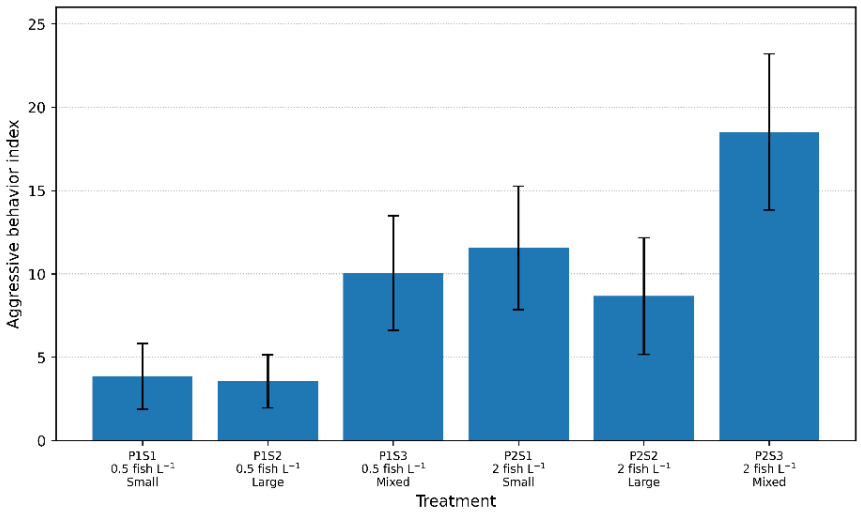



**Figure. 1**. Aggressive behavior index of barramundi juveniles reared at different stocking densities and seed-size categories.

The concentration of high AI values in P2S3 is compatible with more frequent encounters at higher density combined with greater size-related dominance in mixed cohorts. More crowding may increase competition and reduce escape space, whereas differences in body size could influence which fish monopolise access to food (Baras & Jobling, 2002; Kestemont et al., 2003). Comparable density-associated cannibalism and size-dispersion responses have been reported for Asian seabass in recirculating systems (Khan et al., 2022, 2023; Ribeiro et al., 2015). However, the present result should be interpreted as an association within six treatment combinations, not proof that density alone caused aggression: density and cohort structure may operate together with feeding opportunity and individual differences.

P2S3 showed the greatest reported feeding-area dominance (4.12 ± 0.76) but the lowest feeding-activity score (2.83 ± 0.38). This contrast is consistent with an unequal-feeding-access hypothesis, under which dominant fish occupy the feeding area while other individuals exhibit avoidance or reduced feeding attempts. Nevertheless, these qualitative scores are not measurements of individual ration, ingestion, or appetite. Studies of predatory fish larvae have shown that competition and heterogeneous growth can interact with cannibalism (Kestemont et al., 2003), whereas higher feeding frequency delayed size dispersion in barramundi (Ribeiro et al., 2015). Future work should pair ethograms with individual feeding success or video-identified access to pellets to test this proposed mechanism.

### 3.2. Injury, missing fish, and cannibalism-related events based on six-hour observation

Across all treatments, the six-hour inventories documented 81 injury observations, 137 fish not recovered and therefore classified as suspected cannibalism, and seven Type II entries assigned in the inventory (**Table 4**). The separate behavioural ethogram recorded 28 predation-related observations across the six treatments (**Table 3**). These are different reporting streams: the 28 records may include more than one observation of a predator–prey interaction, while the seven records denote inventory-assigned complete-cannibalism losses. Their numerical difference cannot be used to estimate undocumented events or to infer that seven of the 28 observations necessarily produced the seven losses. The pattern of greater injury and disappearance in the high-density mixed-size groups remains descriptive evidence of an elevated-risk setting, not independent confirmation of the cause of every missing fish.

**Table 4**. Injury and cannibalism-related events of barramundi juveniles based on six-hour observation log.

| Treatment | Injured fish (fish unit$^{-1}$) | Missing fish suspected as cannibalism (fish unit$^{-1}$) | Type II cannibalism (fish unit$^{-1}$) | Total cannibalism-related loss (fish unit$^{-1}$) |
|---|---|---|---|---|
| P1S1 | 0.67 ± 0.58 | 1.00 ± 1.00 | 0.33 ± 0.58 | 1.33 ± 1.15 |
| P1S2 | 0.67 ± 0.58 | 1.00 ± 1.00 | 0.00 ± 0.00 | 1.00 ± 1.00 |
| P1S3 | 1.00 ± 1.00 | 3.33 ± 3.06 | 0.00 ± 0.00 | 3.33 ± 3.06 |
| P2S1 | 6.67 ± 1.53 | 11.33 ± 4.04 | 1.00 ± 1.73 | 12.33 ± 3.06 |
| P2S2 | 7.67 ± 2.52 | 13.67 ± 4.51 | 1.00 ± 1.00 | 14.67 ± 3.21 |
| P2S3 | 10.33 ± 3.51 | 15.33 ± 4.73 | 0.00 ± 0.00 | 15.33 ± 4.73 |

Values are presented as mean ± standard deviation from three replications.

A critical distinction is that the table presents injury observations, missing fish, and assigned Type II losses as different data streams. In particular, the last column corresponds to the sum of the missing-fish and Type II categories as reported, whereas injured-fish records are not added to this loss total. All means should therefore be interpreted in their original recording units rather than as nonoverlapping numbers of uniquely identified individuals

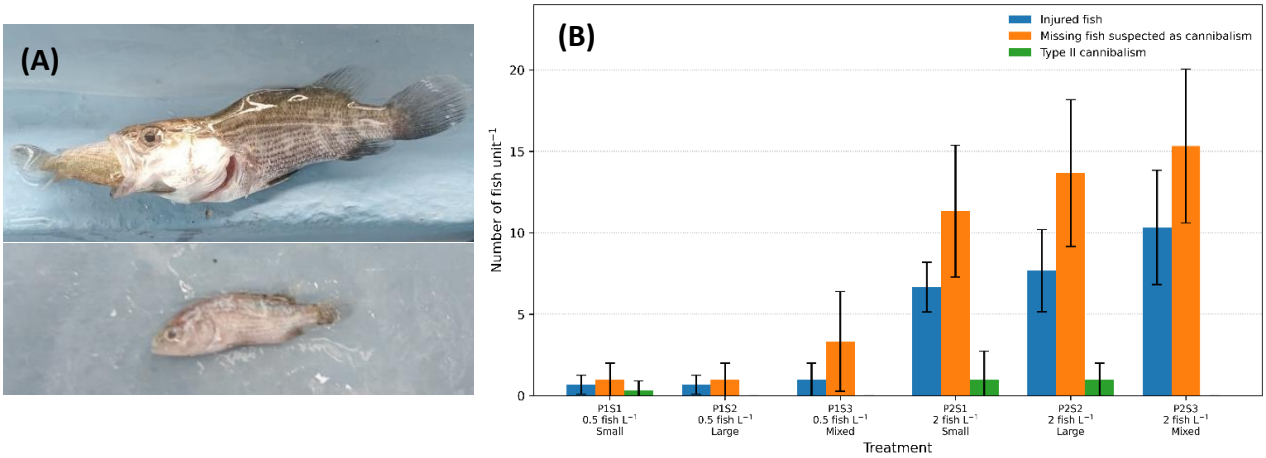



**Figure. 2.** Cannibalism-related events in barramundi *(Lates calcarifer*) juveniles during the 30-day nursery period: (A) observed cannibalistic predation of a larger juvenile on a smaller conspecific; (B) injured fish and missing fish suspected as cannibalism across stocking density and seed-size treatments.

In the three high-density treatment combinations, 121 of the 137 missing fish and 74 of the 81 recorded injured-fish observations were reported. These totals show that absolute numbers of incidents were greater in high-density containers. However, with 20-L units, the initial stock was 10 fish at 0.5 fish $L^{-1}$ and 40 fish at 2 fish $L^{-1}$, so absolute counts are not directly comparable across densities. Based on the published container-level means in **Table 4**, missing fish represented approximately 10.0%, 10.0%, and 33.3% of initially stocked fish in P1S1, P1S2, and P1S3, versus 28.3%, 34.2%, and 38.3% in P2S1, P2S2, and P2S3. These are descriptive percentages calculated from rounded treatment means and initial stocking, not new individual-level data or tests of treatment differences.

P2S3 combined the highest AI, injury observations, and missing-fish counts, providing convergent descriptive evidence of a high-risk rearing condition. Nevertheless, missing fish remain suspected losses: a direct predation record or corroborating evidence is needed for confirmation. The association between crowding and cannibalism may be modified by feeding frequency and population structure, as illustrated by experimental barramundi studies (Khan et al., 2022; Ribeiro et al., 2015). The combination of frequent injury checks, standardised population accounting, and targeted video observation is consequently more defensible than treating disappearance as a direct measure of cannibalism.

**Table 3** contains 28 predation-related behavioural observations, including 14 in P2S3. Table 4 instead contains seven inventory-assigned Type II fish-loss entries, with none recorded for P2S3. This discrepancy in category totals is retained and made explicit rather than obscured: the ethogram encompassed attacks and ingestion-related observations, whereas Type II referred to a specific inventory-loss classification. The archived summary is insufficient to determine whether these events overlapped, whether an observation was repeated, or why no P2S3 event was assigned to Type II. Accordingly, the paper reports the two endpoints separately and does not claim to reconcile individual events. Follow-up recording should use a unique fish/event identifier, timestamp, confirmation of ingestion, and an explicit rule for converting behaviour observations into fish-loss classifications (Hecht & Pienaar, 1993; Khan et al., 2023).

### 3.3 Size heterogeneity and potential cannibal emergence

Size heterogeneity increased over the 30-day nursery period, especially among fish initially placed into mixed-size groups. The highest final body-weight CV was recorded in P1S3 (60.49%), followed by P2S3 (46.97%). Values in the other treatments were lower at the final sample (32.71–35.70%; **Table 5**; **Figure 3**). These measurements show a widening body-mass distribution, but because the mixed-size groups already began with greater heterogeneity, the higher final CV should not be attributed solely to post-stocking growth divergence. Selective removal of smaller individuals by death or suspected cannibalism may also change CV among survivors.

**Table 5**. Development of body weight coefficient of variation and potential cannibal emergence in barramundi juveniles.

| HAP | P1S1 | P1S2 | P1S3 | P2S1 | P2S2 | P2S3 |
|---|---|---|---|---|---|---|
| 0 | 15.31 | 20.31 | 28.36 | 25.78 | 12.62 | 22.94 |
| 10 | 25.39 | 18.62 | 35.89 | 24.47 | 16.21 | 24.53 |
| 20 | 28.09 | 24.40 | 39.52 | 28.72 | 29.53 | 33.80 |
| 30 | 35.70 | 33.25 | 60.49 | 35.63 | 32.71 | 46.97 |
| Potential cannibal at H30 (fish unit$^{-1}$) | 0.00 | 0.00 | 0.67 | 0.33 | 0.00 | 0.33 |

HAP = day of observation; values of CV body weight are expressed as percentage.

The weight CV measurements in Table 5 cover days 0, 10, 20, and 30. The series is descriptive and should not be interpreted as a repeated-measures significance test. Because the initial mixed-size treatments were already heterogeneous, a higher final CV does not establish a treatment effect without an analysis that accounts for starting dispersion and changes in cohort membership

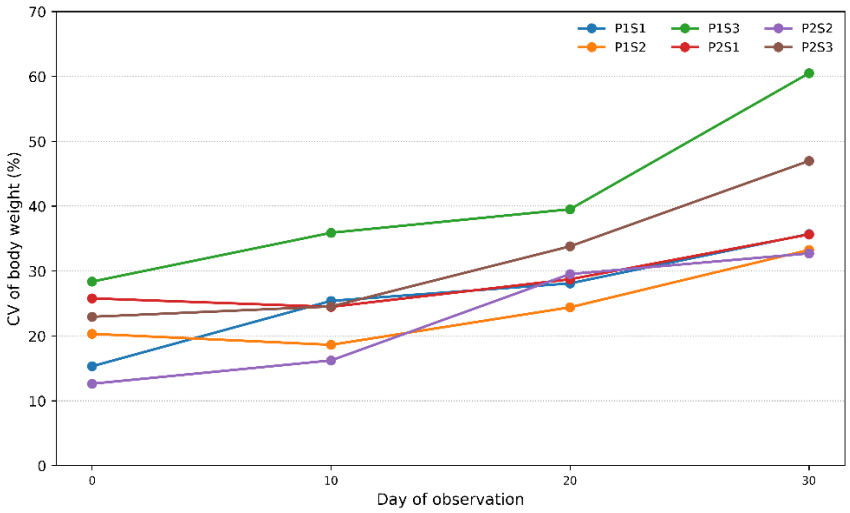



**Figure. 3**. Development of body weight coefficient of variation in barramundi juveniles from HAP 0 to HAP 30.

The trajectory of weight CV is consistent with persistent or increasing cohort heterogeneity in cultured predatory fish (Kestemont et al., 2003). Differences in ration access and dominance could contribute to depensatory growth, although the present records cannot separate growth variation from changes in survivor composition. In juvenile barramundi, Ribeiro et al. found that feeding frequency and density affected size dispersion and the temporal emergence of cannibals (Ribeiro et al., 2015). Accordingly, the high final CV values in mixed-size groups support including routine size checks in nursery surveillance, but do not, by themselves, demonstrate that dispersion occurred before each cannibalism event.

The originally designated potential cannibals were detected in P1S3 (0.67 fish per container), P2S1 (0.33), and P2S3 (0.33) at day 30 (**Table 5**). These counts represent the study's weight-based screening definition and not observed predatory identity. Ribeiro and Qin showed experimentally that barramundi cannibalism is constrained by predator–prey size compatibility and related morphology (Ribeiro & Qin, 2013). Weight outliers therefore warrant closer inspection, particularly when they co-occur with injuries and aggressive interactions, but a 2–3-fold weight ratio should not be described as a validated universal threshold.

A notable contrast was that P1S3 had the greatest final weight CV, whereas P2S3 had the highest aggression index and largest reported missing-fish count. Thus, extreme size dispersion was not the only characteristic linked to the observed loss pattern. Other conditions, including encounter rates, feeding opportunities, or aggression, could contribute (Baras & Jobling, 2002; Ribeiro et al., 2015). The original factorial design is suitable for testing density × size-category hypotheses, but the current summary tables do not provide a complete inferential analysis to isolate those effects. The joint interpretation remains an experimentally informed hypothesis rather than proof of synergism.

*3.4 Relationship among aggressive behavior, size heterogeneity, cannibalism risk, and survival*

The reported container-level correlation matrix showed positive associations of AI with suspected total cannibalism (r = 0.620, p = 0.006), recorded cannibalism (r = 0.702, p = 0.001), and actual predation (r = 0.704, p = 0.001), as well as a negative association with survival (r = −0.578, p = 0.012). Final body-weight CV was positively related to recorded cannibalism (r = 0.570, p = 0.014) but not significantly associated with survival (r = −0.419, p = 0.084; **Table 6**). These values are reproduced from the submitted analysis. They support contemporaneous co-variation, not an independently validated predictive model.

**Table 6**. Correlation among early indicators and cannibalism risk in barramundi juveniles.

| Variable 1 | Variable 2 | Pearson's r | p-value | Interpretation |
|---|---|---|---|---|
| Aggressive behavior index | Suspected total cannibalism | 0.620 | 0.006 | Significant positive correlation |
| Aggressive behavior index | Recorded cannibalism | 0.702 | 0.001 | Significant positive correlation |
| Aggressive behavior index | Survival rate | -0.578 | 0.012 | Significant negative correlation |
| Aggressive behavior index | Final CV of body weight | 0.378 | 0.122 | Positive but not significant |
| Aggressive behavior index | Actual predation | 0.704 | 0.001 | Significant positive correlation |
| Final CV of body weight | Recorded cannibalism | 0.570 | 0.014 | Significant positive correlation |
| Final CV of body weight | Survival rate | -0.419 | 0.084 | Negative but not significant |
| Suspected total cannibalism | Survival rate | -0.912 | <0.001 | Strong significant negative correlation |

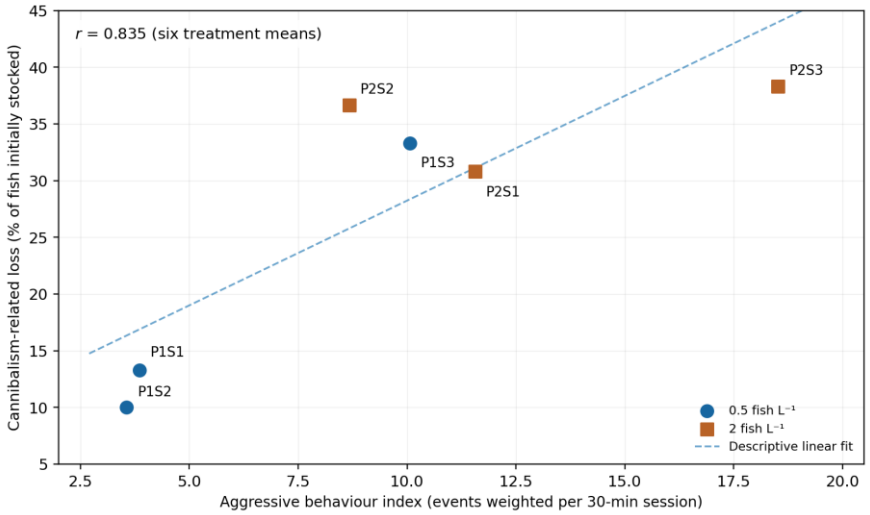



**Figure. 4**. Aggressive behaviour index versus reported cannibalism-related loss (% initially stocked) reconstructed from six treatment means (r = 0.835).

**Figure 4** was reconstructed using only reproducible values already displayed in the manuscript: the six treatment means of AI in Table 3 and the reported total cannibalism-related loss per container in **Table 4**. The plotted percentage equals 100 × [**Table 4** loss count per container] / [initial number of fish per container], using 10 fish for P1 and 40 fish for P2. The six treatment-level pairs yield a descriptive Pearson r = 0.835, calculated from rounded treatment means. This is an ecological correlation across six group summaries, not the container-level correlation (r = 0.702) for the originally defined 'recorded cannibalism' variable in **Table 6**. Its value is not evidence of prospective prediction or of confirmed predation, and no significance test is inferred from the graph.

The correlations in Table 6 refer to the earlier analysis of container-level endpoints. In contrast, the revised Figure 4 depicts the percentage of the Table 4 composite loss outcome against treatment-mean AI. The different analytical unit (six treatment means rather than 18 containers), different loss definition, and conversion to initial-stock percentages mean that r = 0.835 and r = 0.702 are not estimates of an identical association. They should not be interpreted as conflicting values for one test or as independent replication. Both are descriptive contemporaneous associations; directionality and utility as an early-warning predictor remain untested. Behavioural work in fish supports investigating the biological link between aggression and predation, while cannibalism studies in barramundi underscore the role of stocking density and feeding context (Filby et al., 2010), (Khan et al., 2022, 2023; Ribeiro et al., 2015).

Between-species comparisons reinforce the need for restraint in interpreting these correlations. In juvenile pikeperch, intermediate stocking density was associated with lower cannibalism at the smallest stage, whereas

larger stages showed little or no cannibalism despite differing densities (Kozłowski & Piotrowska, 2024). In tropical gar larvae, attack frequency and size heterogeneity did not always peak under the same treatment (Sepúlveda-Quiroz et al., 2024). Therefore, the alignment of aggression, size dispersion, and loss observed in P2S3 is informative for this barramundi experiment, but cannot be generalised as a fixed ecological law across cultured predatory fish.

The positive relation between final body-weight CV and recorded cannibalism ($r = 0.570$, $p = 0.014$) suggests that size structure is relevant to the observed events. Nevertheless, the end-point CV is not a temporally prior exposure, and individual growth differences could be both a contributor to and a consequence of selective predation. The relationships should therefore be treated as associations, not evidence that changing CV caused cannibalism. Monitoring CV may help identify cohorts for more frequent checks, especially where mixed sizes and injuries coexist, but an operational trigger value has not been validated (Kestemont et al., 2003; Ribeiro et al., 2015; Ribeiro & Qin, 2013).

The strongest reported association was between suspected total cannibalism and survival ($r = -0.912$, $p < 0.001$). This should not be interpreted as independent validation of cannibalism as the principal cause of mortality. Both quantities are derived partly from the same fish-accounting process: when fish disappear, the count surviving can decline by construction. Therefore, mathematical coupling can inflate the apparent strength of the inverse relation. Moreover, 'suspected' fish loss is not equivalent to confirmed ingestion. The coefficient is retained as a descriptive statistic, with this caveat made explicit; confirmation would require verified predation events and exclusion of other causes of disappearance.

### 3.5 General interpretation and nursery management implications

Together, the results describe a high-risk observational profile for juveniles maintained at 2 fish $L^{-1}$ with mixed initial size: elevated aggressive interactions, many injury reports, more missing fish, and considerable body-size dispersion. The appropriate interpretation is 'candidate monitoring indicators associated with cannibalism-related outcomes', rather than evidence that a validated early-warning threshold has been established. This distinction matters because the six-hourly inventory and behavioural summaries do not demonstrate how many hours or days each behavioural change preceded a later loss.

Aggression and size heterogeneity reflect complementary aspects of nursery dynamics. The former describes current interactions; the latter describes the distribution of body sizes that may permit asymmetric predation. Both can be shaped by feeding management, social environment, and mortality-related changes in cohort composition. Research in European perch and European seabass larvae found that interactive and environmental factors jointly influenced growth and size dispersion (Kestemont et al., 2003). In pikeperch (*Sander lucioperca*), the relationship between stocking density, juvenile size, growth, and cannibalism varied among size classes and experimental conditions (Kozłowski & Piotrowska, 2024). These species comparisons caution against interpreting a single density or CV value as a universal risk boundary.

For hatchery implementation, a reasonable response to elevated chasing, biting, injury, or increasing dispersion is intensified observation and examination of feed distribution, density, and need for size grading, rather than automatically declaring cannibalism from an isolated symptom. In tropical gar (Atractosteus tropicus), stocking density and feeding conditions altered attack rates and size heterogeneity, illustrating that aggression-related responses are species- and context-dependent (Sepúlveda-Quiroz et al., 2024). In barramundi, grading and coordinated feeding management are established practical considerations (Lesmana et al., 2025; Ribeiro et al., 2015). The original data support monitoring these variables together, but further work is needed to determine costs, welfare consequences of repeated grading, and whether a monitoring protocol prevents subsequent stock loss. General feed-efficiency literature provides supporting husbandry context but should not be presented as evidence from the present experiment (Maser et al., 2025).

A recent barramundi-focused literature synthesis by Lesmana et al. (Lesmana et al., 2026) integrated morphological constraints, prey-size vulnerability, feeding competition, and energetic explanations of intracohort cannibalism. It supports examining behaviour and size structure together but is a synthesis, rather than independent experimental validation of the candidate indicators in the present trial. In a separate controlled study on Asian seabass fry, Perdian et al. (Rifki Perdian et al., 2026) reported lower cannibalism under a particular melatonin treatment, providing evidence that cannibalism-related responses can also be modulated by physiological interventions. Neither publication establishes a predictive aggression-index threshold for the nursery conditions investigated here.

Evidence across additional aquaculture species cautions against treating density or grading as universally beneficial. In juvenile lumpfish, Perry et al. (Perry et al., 2024) examined aggressive responses in relation to light conditions, density, and fish size. A 2026 meta-analysis covering 32 fish species found that size grading often reduced cannibalism but could be accompanied by growth-related trade-offs that varied among species

(Wu et al., 2026). Together, these studies support a context-dependent nursery strategy: monitor the changing distribution of body size and injury, standardise behavioural scoring, and test management adjustments prospectively rather than prescribing a single density or grading interval from the current descriptive results

Overall, the six treatment combinations indicate that high-density mixed-size rearing coincided with the most intense observed aggression and substantial injury and suspected fish loss. Size dispersion, behavioural-event counts, and inventory losses each provide different information; none should replace confirmation of predation. Thus, integrated records may improve situation awareness during nursery management, but time-resolved predictive validation and independent replication are needed before claiming reliable early warning.

## 4. Conclusion

In the 30-day barramundi nursery assessment, the high-density mixed-size group (P2S3) had the highest aggressive behaviour index (18.52 ± 4.68 per 30-min session), frequent chasing and biting, and the largest reported container-level missing-fish count (15.33 ± 4.73). The greatest final body-weight CV occurred instead in the low-density mixed-size group (P1S3; 60.49%), compared with 46.97% in P2S3. These differences suggest that aggression and size heterogeneity describe related but non-identical dimensions of cannibalism-associated nursery conditions. Recorded injuries and missing individuals complement direct predation observations but do not prove the cause of each loss.

The reported positive correlations of aggression and final size dispersion with cannibalism-related outcomes support their use as candidate surveillance variables, not validated predictors or causal determinants. The strong inverse correlation between suspected cannibalism and survival is partly affected by shared fish-counting components and must not be used as independent proof of cannibalism. Nursery monitoring should combine behavioural observations, size grading assessment, feeding distribution, and careful loss accounting. Future studies should link time-stamped aggression to later verified predation, clarify event definitions, and test intervention thresholds in additional cohorts and commercial-scale systems.

## 5. Acknowledgements

The authors would like to express their sincere gratitude to the Marine Aquaculture Development Center, Batam, Ministry of Marine Affairs and Fisheries, for providing research facilities, technical assistance, and access to barramundi juvenile nursery activities during the study. The first author also gratefully acknowledges the Government of Indonesia for supporting doctoral study through the Beasiswa Pendidikan Indonesia (BPI) 2023 for lecturers in the Doctoral Program in Marine Science, Universitas Riau.

## 6. Conflict of Interest

The authors declare that there is no financial or non-financial conflict of interest related to the publication of this article.

## References

Baras, E., & Jobling, M. (2002). Dynamics of intracohort cannibalism in cultured fish. *Aquaculture Research*, *33*(7), 461–479. https://doi.org/10.1046/j.1365-2109.2002.00732.x

Duk, K., Pajdak, J., Terech-Majewska, E., & Szarek, J. (2017). Intracohort cannibalism and methods for its mitigation in cultured freshwater fish. *Reviews in Fish Biology and Fisheries*, *27*(1), 193–208. https://doi.org/10.1007/s11160-017-9465-2

Filby, A. L., Paull, G. C., Hickmore, T. F., & Tyler, C. R. (2010). Unravelling the neurophysiological basis of aggression in a fish model. *BMC Genomics*, *11*(1), 498. https://doi.org/10.1186/1471-2164-11-498

Hecht, T., & Pienaar, A. G. (1993). A Review of cannibalism and its implications in fish larviculture. *Journal of the World Aquaculture Society*, *24*(2), 246–261. https://doi.org/10.1111/j.1749-7345.1993.tb00014.x

Kestemont, P., Jourdan, S., Houbart, M., Mélard, C., Paspatis, M., Fontaine, P., Cuvier, A., Kentouri, M., & Baras, E. (2003). Size heterogeneity, cannibalism and competition in cultured predatory fish larvae: biotic and abiotic influences. *Aquaculture*, *227*(1–4), 333–356. https://doi.org/10.1016/S0044-8486(03)00513-1

Khan, Md. S. K., Salin, K. R., Yakupitiyage, A., Tsusaka, T. W., Nguyen, L. T., & Siddique, M. A. M. (2023). L-Tryptophan mitigates cannibalism and improves growth of Asian seabass, *Lates calcarifer* reared in a RAS system. *Aquaculture Journal*, *3*(3), 168–180. https://doi.org/10.3390/aquacj3030014

Khan, Md. S. K., Salin, K. R., Yakupitiyage, A., Tsusaka, T. W., Shrestha, S., & Siddique, M. A. M. (2022). Effect of stocking density and tank colour on nursery growth performance, cannibalism and survival of

the Asian seabass *Lates calcarifer* (Bloch, 1790) in a recirculating aquaculture system. *Aquaculture Research*, *53*(6), 2472–2483. https://doi.org/10.1111/are.15765

Kozłowski, M., & Piotrowska, I. (2024). Effect of stocking density on growth, survival and cannibalism of juvenile pikeperch, Sander lucioperca (L.), in a recirculating aquaculture system. *Aquaculture International*, *32*(3), 3587–3595. https://doi.org/10.1007/s10499-023-01339-6

Lesmana, I., Effendi, I., Suharman, I., & Putra, I. (2026). Morphological, behavioural, and energetic mechanisms of cannibalism in juvenile barramundi (*lates calcarifer*): a literature synthesis with field-based hatchery perspective. *Jurnal Perikanan Unram*, *16*(2), 1111–1127. https://doi.org/10.29303/jp.v16i2.2239

Lesmana, I., Effendi, I., Suharman, I., Putra, I., Ruthmawati, A., & Andesca, Y. D. (2025). Managing Cannibalism and Improving Larval Survival in Barramundi Hatchery. *Asian Journal of Aquatic Sciences*, *8*(2), 203–213. https://ajoas.ejournal.unri.ac.id/index.php/ajoas/article/view/3112

Liu, X., Xia, J., Pang, H., & Yue, G. (2017). Who eats whom, when and why? Juvenile cannibalism in fish Asian seabass. *Aquaculture and Fisheries*, *2*(1), 1–9. https://doi.org/10.1016/j.aaf.2016.12.001

Maser, W. H., Muhtadi, A., Ritonga, A., Almira, D., Panjaitan, F., Sari, N., Sinurat, R. R. R., Kembaren, N. P. B. S., Purba, T. W. A., Nababan, D., Andari, E., Harahap, M. H. F., & Pasaribu, R. A. (2025). Review of the enzymes utilization in the feed for indigenous Indonesian fish. *AQUACOASTMARINE: Journal of Aquatic and Fisheries Sciences*, *4*(1), 1–10. https://doi.org/10.32734/jafs.v4i1.20246

Pereira, L. S., Agostinho, A. A., & Winemiller, K. O. (2017). Revisiting cannibalism in fishes. *Reviews in Fish Biology and Fisheries*, *27*(3), 499–513. https://doi.org/10.1007/s11160-017-9469-y

Perry, S. A., Fairchild, E. A., & Jellison, B. M. (2024). The effects of light, rearing density, and fish size in culturing juvenile Lumpfish. *North American Journal of Aquaculture*, *86*(4), 401–412. https://doi.org/10.1002/naaq.10347

Pham, V. K., Truong, H. P., Nguyen, D. K., & Nguyen, N. H. (2020). Genetic component of cannibalism in Asian seabass *Lates calcarifer*. *Applied Animal Behaviour Science*, *231*, 105074. https://doi.org/10.1016/j.applanim.2020.105074

Ribeiro, F. F., Forsythe, S., & Qin, J. G. (2015). Dynamics of intracohort cannibalism and size heterogeneity in juvenile barramundi (*Lates calcarifer*) at different stocking densities and feeding frequencies. *Aquaculture*, *444*, 55–61. https://doi.org/10.1016/j.aquaculture.2015.03.029

Ribeiro, F. F., & Qin, J. G. (2013). Modelling size-dependent cannibalism in barramundi *Lates calcarifer*: cannibalistic polyphenism and Its implication to aquaculture. *PLoS ONE*, *8*(12), e82488. https://doi.org/10.1371/journal.pone.0082488

Rifki Perdian, M., Sudrajat, A. O., Carman, O., & Arfah, H. (2026). Cannibalism control of Asian seabass <i>Lates calcarifer</i> fry by melatonin hormone administration. *Jurnal Akuakultur Indonesia*, *25*(1), 70–80. https://doi.org/10.19027/jai.25.1.70-80

Sepúlveda-Quiroz, C. A., Alvarez-Villagomez, C. S., Álvarez-González, C. A., Jiménez-Martínez, L. D., Pérez-Jiménez, G. M., Asencio-Alcudia, G. G., Mendoza-Porras, O., López-Hernández, J. F., Pérez-Morales, A., Galaviz-Espinoza, M. A., Tovar-Ramirez, D., Ramírez-Martínez, C., & Martínez-García, R. (2024). Intra-cohort cannibalism and aggressive behavior in tropical gar (*Atractosteus tropicus*) larvae: Effects of stocking density and starvation. *Aquaculture*, *593*, 741324. https://doi.org/10.1016/j.aquaculture.2024.741324

Wu, C., Zhu, Z., Wen, Y., Zhu, S., Liu, Y., Liu, K., Shih, Y., Ye, Z., Liu, X., & Zhao, J. (2026). Does Size Grading Improve Fish Farming? Evidence From a Meta-Analysis. *Reviews in Aquaculture*, *18*(3). https://doi.org/10.1111/raq.70162