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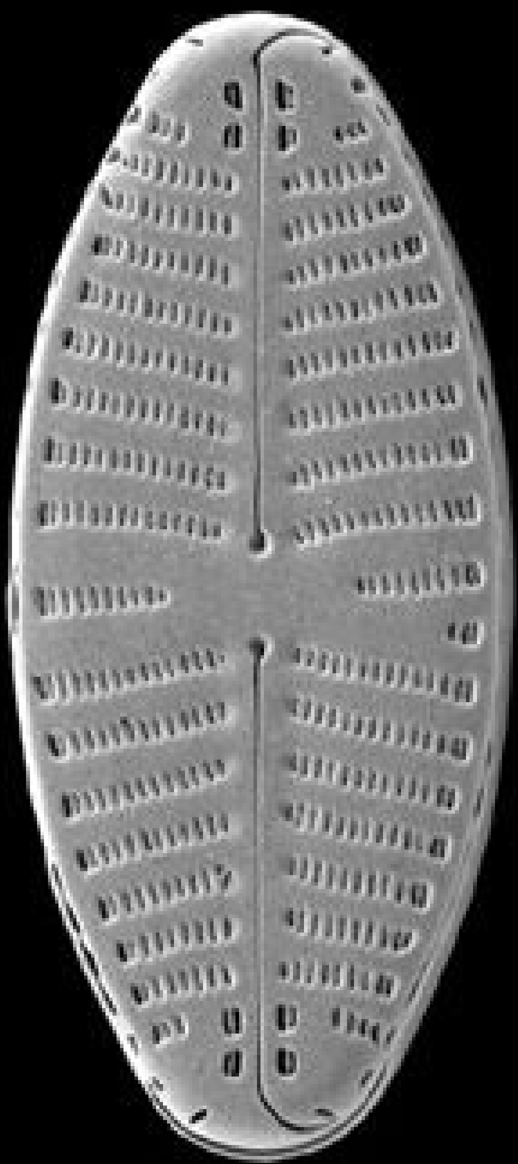

SUSTAINABLE AQUATIC RESEARCH

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SUSTAINABLE AQUATIC RESEARCH
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How sustainable is sustainable living without sustainable aquatic research?

Editorial Team

Aims & Scope

Aims

SUSTAINABLE AQUATIC RESEARCH (SAquaRes) aims to play an important role in advancing and understanding of aquatic sustainability. The most important aim of SAquares is "to put the research on aquatic sustainability at the focus of science. Sustainable life in the world will be realized with a sustainable aquatic ecosystem."

Scope

The scope of SAquaRes includes papers from non-traditional scientific areas such as sustainability science, social-ecological systems, ornamental, conservation, and restoration, and also the traditional priorities of its sections related to aquatic environments *(the list below is given in alphabetical order)*:

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- Marine and Freshwater Pollution
- Seafood Quality and Safety
- Sustainable and Renewable Resources
- Sustainable Aquatic Ecosystem
- Sustainability assessment and design of aquacultural systems and decision support tools
- Water Quality and Pollution
- Wastewater Treatment
- And more research focused on sustainability

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EDITORIAL

The Publication Game in the Aquatic Sciences– an Editor in Chief's Perspective

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The editorial in the last issue was evocative and thought provoking (Steinberg, 2024). Consequently, it is appropriate to include an Editor in Chief's perspective on the manuscripts that are received and considered for publication. It is realized that the publication process is stressful for the authors, but success is euphoric. Authors strive to publish in top class refereed international journals with success contributing to career security and advancement. The utopian desire of editors is to publish well-written manuscripts describing excellent work that will be well received by the readership and contribute to the all-important journal metrics. In short, we live in a period dominated by impact factors, and the number of citations, article downloads and reads. There may be contractual obligations with the publisher regarding the number of articles to be accepted and published within a defined period. In short, there is pressure on editors and authors. So, what is the reality of the situation. To dispel one myth, not all submissions lead to publications. It is not unusual that only a small minority of the submissions are actually published.

The first stage of the process is that the author(s) carries out a piece of work that is considered to be worthy of publication. Then, a decision needs to be made about which journal to approach. In our subject area of aquaculture, you would be surprised by the number of submissions that bare little or no relationship to the subject of the journal. Indeed, aquaculture may not even be mentioned in the text. This raises the question about why have the authors submitted their work to an aquaculture journal? Our message is to choose an appropriate journal for the work otherwise the submission will not progress any further. However, if the manuscript is considered to have merit, then the editors may suggest resubmission to another more appropriate journal. It should be emphasized that international journals are only interested in work of relevance to multiple countries, i.e. of international relevance. Work only of local interest is unlikely to be accepted by an international journal. Once chosen, the format of the journal needs to be followed otherwise rejection will occur. You would be surprised at the number of times that manuscripts do not follow the Instructions for Authors. These manuscripts do not progress any further, and are returned to the authors. As many journals publish in English, it is important that the manuscript is linguistically and grammatically correct [in English]. Otherwise, the editor is likely to recommend that the authors consult with somebody fluent in English before the manuscript will be considered any further.

A major reason for rejection is plagiarism [including self-plagiarism, i.e. when the author uses text that has already been published]; this is highlighted by software that is used by most if not all publishers to detect similarity levels with other work in the data base. High levels of similarity to other work will lead to an automatic rejection. These quality checks will weed out a good number of manuscripts that are returned to the authors. If the manuscript has survived so far then it may be scrutinized further by editors for content

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and style, and then sent to referees.

At this point, it is prudent to consider research and review articles. The former needs to contain new information that advances knowledge of the subject. We do not welcome manuscripts that essentially reiterate what is already known without adding a substantive amount of new information. Nicely written manuscripts representing a well-rounded piece of original research are so much better and will receive greater support from the editor than the infuriating habit of subdividing the work to maximize the number of publications.

A common mistake with review articles is that they summarize the literature without detailing the strengths and weaknesses of publications, and the knowledge gaps that need to be addressed. It is not unusual for review manuscripts to resemble the introductions from student theses rather than carefully constructed arguments suited for publication in scientific journals.

This raises the question about how journals ensure the quality of submitted manuscripts? The short answer is a reliance on referees, who mostly perform the task for little or no reward. However, it is a personal expectation that those who submit manuscripts to a journal should be prepared to review for the same journal. Who are these referees and how are they chosen? Apart from members of editorial boards and individuals known and respected by editors, reliance is placed on the use of software to identify and suggest potential referees. In addition, the authors may be allowed to suggest referees, subject to certain constraints. Conversely, authors may request that certain individuals are not appointed as referees. Software may indicate potential conflicts of interest, and reveal the background of the suggested referees, including field of interest, number of publications and citations, and reviewing history, i.e. the number of invitations, acceptances, and delivery rate, and the time frame. Editors realize that potential referees are already likely to be overworked, and it may take dozens of invitations to secure the minimum number of acceptances. With some manuscripts, the required number of referees are obtained, and excellent reviews are furnished within a comparatively short period of time. The other extreme is that the response by the referees is tardy in terms of timeliness and the quality of the review. In some cases, none of the invitations are accepted leading to yet more searching. Alas, not all acceptances result in the delivery of completed referee reports despite reminders [and pleading!]. This delays the publication process as more referees will need to be sought and appointed. If all goes according to plan, at some point, the requisite number of referee reports will have been received, and the editor will scrutinize the responses to make a decision on the acceptability (or otherwise) of the manuscript. The editor will look for comments concerning the use of adequate numbers of replicate experiments, and the use of appropriate controls. Are the data adequate quantitatively and qualitatively? Is there any indication of poor work? If there is a consensus of opinion by the referees then the decision is relatively straightforward. However, it is not so unusual that referees will have opposing views, which the editor needs to resolve, and may need the opinions of yet more referees before reaching a decision, and informing the author about whether the manuscript will be rejected, accepted or more likely in need of revision. In many cases, the author will be requested to revise the manuscript within a specified timeframe. A common mistake particularly among novice authors is to rush into making revisions, and to ignore many of the suggestions to improve their manuscript. Some comments will be more important than others – ignore them at your peril! Revised manuscripts may be reviewed again, with the editor taking the final decision about acceptability. It is unlikely that editors will have expertise in all areas covered by the journal. Therefore, the views of referees are important in making an informed decision about the quality of the manuscript and the work that it describes. It is a sad fact that the majority of manuscripts will be rejected for one or more of the reasons described above. Many of the rejected manuscripts will be improved by the authors [including the addition of more data and/or a major re-write] and resubmitted or sent to other journals.

If all goes well, only high-quality articles will be published in refereed journals, and knowledge will be extended. Are such utopian dreams realized? Well, the reality is often very different. Despite the good intentions of journals and their editors, some articles of dubious standard survive scrutiny, and are published. In some cases, manuscripts may present only the best, most convincing data; the rest are overlooked because they do not fit the narrative presented by the author. Most of us will have encountered publications that state "representative/typical data show….." whereas the reality is different, i.e. the best date are included, and the rest are ignored. Multiple articles [= paper mills], often in different journals, may focus on a common theme, and as a group provide limited new knowledge. The best articles will be remembered, and their content used by other scientists. The worst articles may be questioned in Opinions or Letter to the Editor sections of journals. Punitive action may be taken against the minority of authors who falsify their data or attempt to duplicate their articles in two or more journals. These cases of misconduct are treated seriously, and will be investigated by the journal/publisher. It goes without saying that journals will retract these papers. The other articles, which are neither the best nor the worst, are apt to be largely forgotten with time.

Could we do any better – what developments may we see in the future? We may anticipate that Artificial Intelligence (AI) will significantly revolutionize the publication process, particularly involving the evaluation stage, although there is concern that AI could be used to write manuscripts (Khalifa and Albadaawy, 2024)! Clearly, while embracing the transformative potential of AI, it is necessary to maintain a dynamic balance between the immutable values of academic rigor and ethical research (Glumbe et al., 2024). Looking at the history of scientific publishing, we have progressed from an entirely manual system [i.e. involving submission of multiple hard copies including photographs to a journal office followed by the dispatch of the manuscript to referees chosen from the personal knowledge of the editor, who makes the decision about acceptability or otherwise] to a fairly automated Internet-based process. Now, we are at the mercy of software developers, who may or may not involve editors in the development process. Paper has been replaced by computer files. What will be the next step? An electronic system that will receive and assess manuscripts, maybe with the use of referees, and make decisions without the need for direct human intervention? Will referees continue to be used in the future or will there be a reliance on AI? Could the role of the [human] scientific editor be coming to an end? There are clearly interesting times ahead for the publication process. In the meantime, we will continue to strive towards publishing high quality work. The current system is not perfect, but has evolved, and is sufficiently robust to identify problem manuscripts. The initial quality control inspections reject manuscripts because of irrelevance to the journal, poor use of language, disregard to the Instructions for Authors and plagiarism/similarity to other published work. Editors identify obvious issues with the data, such as lack of controls or replicates. All this happens before the manuscript is sent to referees, who are often highly critical. Most published manuscripts will have been revised as a result of critical comments by referees and editors.

The developments in the publication process have been met with a veritable explosion in the number of manuscripts submitted to journals posing tremendous pressure on the editors to deal with them in a timely manner for the benefit of authors and journals alike. Many submissions will be culled during the initial quality checks. The rest need to be assessed in terms of the content. This is the principle role of the editors and referees. However, for the system to work effectively, referees need to provide fair, impartial comment. We do not need false praise from "friends" or antagonistic comments from competitors. The reports guide the editor to make informed judgements. Could the process by improved? Well, we are certainly open to suggestions! There are clearly interesting times ahead.

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RESEARCH PAPER

Dietary available phosphorus restriction and skeletal integrity in stomachless fish *Gnathopogon caerulescens* and *Carassius auratus*: the effects of ferric chloride supplementation

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Citation

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Abstract

Phosphorus is abundant in most feed ingredients and is classified into two forms: available and unavailable phosphorus. Available phosphorus is absorbed in the intestines of fish and used for various physiological needs. Any excess available phosphorus is excreted in urine, which is water-soluble and directly stimulates the growth of algae and macrophytes in surrounding water bodies. Therefore, minimizing the available phosphorus content in feeds to match the exact requirement level of fish is necessary to reduce the environmental impacts of aquaculture and promote its sustainable development. This study aimed to develop a technology to minimize the available phosphorus content in aquaculture feeds using ferric chloride as a phosphorus-binder. In a soybean meal-based diet devoid of inorganic phosphorus, the dietary addition of ferric chloride had no measurable effect on bone ash content or bone formation in experimental fish: *Gnathopogon caerulescens* and *Carassius auratus*, both stomachless fish belonging to the cyprinid family. However, in a purified diet containing a normal concentration of inorganic phosphorus, the dietary addition of ferric chloride decreased the bone ash content of the fish ($p<0.01$). Similarly, in a commercial diet containing inorganic phosphorus, dietary ferric chloride decreased the bone ash content of the fish ($p<0.01$). In conclusion, in diets containing soluble inorganic phosphorus, supplementing with ferric chloride can reduce the available phosphorus content, thereby decreasing the phosphorus burden on surrounding water bodies. However, when reducing the dietary available phosphorus content, it is advisable to occasionally monitor the bone ash content or check for bone deformities in cultured fish to prevent clinical deficiencies.

Introduction

Phosphorus (P) is an essential nutrient present in significant amounts in many feed ingredients. The phosphorus in feed can be classified into two forms: available P and unavailable P. Fish can absorb only the available P. Once absorbed from the intestinal tract, available P is used for various necessary functions within the body. However, any excess P that is not reabsorbed by the kidneys is excreted in urine (Bureau and Cho, 1999;

Sugiura et al., 2000). This urinary P is water-soluble and directly promotes the growth of phytoplankton and aquatic plants in the surrounding waters of aquaculture farms. In other words, excess available P in feed is a primary cause of environmental pollution, leading to eutrophication and harmful algal blooms such as red tides.

As global aquaculture production of fish and shellfish rapidly increases, developing technology to reduce the environmental impact of aquaculture has become an urgent research area to ensure the industry's sustainability (FAO, 2022; Nathanailides et al., 2023). Available P can react with various substances, transforming into unavailable P. Substances that facilitate this transformation are known as P binders. By using a P binder to "remove" available P from feed, the release of water-soluble P in aquaculture wastewater would decrease, thereby mitigating environmental pollution.

Various P binders, mainly used as medications for patients with renal failure (Sekar et al., 2018; Doshi and Wish, 2022) and in sewage treatment plants (Morse et al., 1998; Bashar et al., 2018; Bunce et al., 2018), include calcium compounds, aluminum compounds, and ferric compounds. It was assumed that adding these substances to feed could reduce the available P content easily and cost-effectively. However, to the best of our knowledge, there are no precedents for such experiments in fish. Therefore, the present experiments were conducted to test the hypothesis that ferric chloride, a P binder, could decrease the available P content in feed. The effect was evaluated by examining the skeletal ash content (bone density) and skeletal deformations in experimental fish, which serve as reliable indicators of the P status of fish.

Materials and Methods

Fish

Gnathopogon caerulescens is a small cyprinid gudgeon endemic to Japan, known locally as honmoroko. In its natural habitat, it has a lifespan of about three years and can grow up to 13 cm in total length. It is considered a minor aquaculture species in Japan. *Carassius auratus*, commonly known as the goldfish, is another cyprinid fish bred worldwide as an ornamental fish, with various breeds exhibiting different body shapes and colors. In the present study, we used the common goldfish, which retains the original wild shape. Although both species are omnivorous, *G. caerulescens* is more zoophagous than *C. auratus*.

Experiment 1 (Effects of ferric chloride in a practical diet):

Five test diets were prepared using practical ingredients (Table 1). Soybean meal was autoclaved at 120°C for 10 minutes before use. Blood meal consisted of spray-dried porcine blood cells (AP301, APC Japan, Inc.). Feather meal was purchased locally (grade unknown). Ferric chloride anhydrous ($FeCl_3$; Hayashi Pure Chemical Ind. Ltd., Osaka, Japan) dissolved in tap water was added to the basal diet (Diet 1a) to create Diets 1b through 1e. The same amount of tap water was added to Diet 1a. All diets were pelleted and dried at room temperature. After drying, the pellets were top-coated with liquid fish hydrolysate (1 g/100 g, dry weight basis), dried again, placed in plastic bags, and stored at 4°C until feeding. Vitamins and minerals were not supplemented due to the short experimental duration.

The P-binding equivalent of ferric chloride was calculated (Table 1), assuming a 1:1 stoichiometry—one mole of P binds to one mole of Fe forming insoluble $FePO_4$. Thus, the values indicate the maximum amount of P that may be trapped by the supplemental ferric ion (see Discussion for details). The total P and available P content of the experimental diets (Table 1) were calculated using literature values reported for each feed ingredient (Sugiura, 2018) and the present diet composition. The P availability values determined for stomachless fishes were used for these calculations. The supplemental ferric chloride was not considered when calculating the available P content.

G. caerulescens (mean body weight 0.35 g) and *C. auratus* (mean body weight 1.30 g) were stocked together in 20-L aquaria (30 fish per tank, 1 tank per diet). The fish were reared with recirculating filtered water (25 ± 1°C) with a 9.5-hour photoperiod using LED lights (a short photoperiod was applied to suppress gonadal development). Total P concentration in the recirculating water ranged from 0-0.2 ppm (as P). Fish were fed their respective experimental diets for 30 days, 4 times daily, by hand to apparent satiation.

After rearing, 8 fish from each group and species were analyzed. Small or thin fish suspected of poor feed intake were excluded (the same applied to the following experiments). Growth rates and feed efficiency were not recorded due to the short rearing period (the same applied to the following experiments). Analyses were conducted for vertebral ash content (%, fat-free dry basis) and skeletal deformity.

The method for measuring vertebral ash content was as follows: the entire fish was immersed in water at approximately 80°C to denature soft tissues, after cooling down the vertebrae were carefully removed. The vertebrae were washed with tap water, soaked overnight in a methanol-chloroform mixture (1:1, v/v) for defatting, and dried at 105°C for 3 hours. The entire dried vertebrae (including neural and hemal spines; excluding ribs) were ashed at 550°C for 20 hours, and the ash content (% per dry weight) was determined. Due to individual differences in feed intake (growth) within the same tank, the minimum ash content (among 8 fish per tank) is also shown in the table. Individuals with deformed ribs or spines (neural and hemal spines) were counted and classified into three categories: frankly deformed, slightly deformed, and not deformed.

Table 1 Diet composition (upper rows) and the composition of *Gnathopogon caerulescens* and *Carassius auratus* fed their respective diets (lower rows)

Diet	1a	1b	1c	1d	1e
Soybean meal (g)	50	50	50	50	50
Blood meal (g)	10	10	10	10	10
Feather meal (g)	15	15	15	15	15
Wheat flour (g)	20	20	20	20	20
Canola oil (g)	5	5	5	5	5
$FeCl_3$ anhydrous (g)	0	0.25	0.5	1	2
P-binding eq.[1]	0.000	0.048	0.096	0.191	0.383
Total-P (%)	0.41	0.41	0.41	0.41	0.41
Available-P (%)	0.17	0.17	0.17	0.17	0.17
Gnat body wt (g), mean[2]	1.24	1.18	1.17	1.08	1.20
Feeding activity[3]	3-3	3-2	3-3	3-3	3-3
Mortality (#fish)[4]	1	2	0	4	3
Bone ash (%), mean[5]	34.5	36.3	33.7	32.4	33.1
Bone ash (%), min[5]	29.7	32.4	21.4	24.1	24.4
Rib-def (F:S:N)[6]	5:3:0	6:2:0	6:2:0	6:2:0	4:4:0
Sp-def (F:S:N)[6]	1:2:5	0:1:7	0:2:6	0:3:5	2:2:4
Cara body wt (g), mean[2]	3.55	3.07	3.83	3.44	3.49
Feeding activity[3]	2-2	2-2	2-2	2-2	2-2
Mortality (#fish)[4]	0	0	0	0	0
Bone ash (%), mean[5]	36.8	36.2	40.5	39.7	42.2*
Bone ash (%), min[5]	29.0	31.6	37.3	36.1	35.7
Rib-def (F:S:N)[6]	1:7:0	0:6:2	5:3:0	4:4:0	2:6:0
Sp-def (F:S:N)[6]	0:1:7	0:1:7	0:2:6	0:2:6	0:0:8

[1] P-binding equivalent (g/100g diet): P (g/100g diet) that can be trapped by Fe(III).

[2] *Gnat*: *Gnathopogon caerulescens*, *Cara*: *Carassius auratus.*

[3] Feeding activity (by observation): 0 (no feeding), 1 (low), 2 (moderate), 3 (active). The hyphened numbers indicate the first half and the second half periods.

[4] Mortality: the cumulative number of dead fish.

[5] Bone ash%: Mean represents the average of 8 fish. Values with asterisks are significantly different from Diet 1a (*$p<0.05$; **$p<0.01$). Min represents the lowest value in each treatment group.

[6] The number of fish with rib deformity (Rib-def) or neural-hemal spine deformity (Sp-def): F (frank), S (slight), or N (no) deformity.

Experiment 2 (Effects of ferric chloride in a purified diet):

Four test diets were prepared (Table 2). The basal diet (Diet 2a) was a purified low-P diet containing only 0.07% total P. Diets 2b through 2d included inorganic P in the form of KH_2PO_4, with ferric chloride added to Diets 2c and 2d. Vitamins were not supplemented, except in Diet 2d, to minimize potential reactions with added ferric ions. Additionally, lard was used as the fat source because it contains no vitamin E, which could react with ferric ions. Other diet manufacturing conditions followed those in Experiment 1. *G. caerulescens* (mean body weight 0.67 g) and *C. auratus* (mean body weight 1.41 g) were stocked together in 20-L aquaria (30 fish per tank, 1 tank per diet). The fish were fed their respective test diets for 30 days. Other rearing conditions were the same as in Experiment 1.

After rearing, 6 fish from each group and species were analyzed. The analysis items and methods were the same as in Experiment 1.

Table 2 Diet composition (upper rows) and the composition of *Gnathopogon caerulescens* and *Carassius auratus* fed their respective diets (lower rows)

Diet	2a	2b	2c	2d
Egg white powder (g)	60	60	60	60
Starch (g)	30	30	30	30
Cellulose (g)	3.5	3.5	3.5	3.5
Lard (g)	5	5	5	---
Vitamin mix (g)	---	---	---	5
KH_2PO_4 (g)	0	1.5	1.5	1.5
$FeCl_3$ anhydrous (g)	0	0	2	2
P-binding eq.[1]	---	---	0.38	0.38
Total-P (%)	0.07	0.41	0.41	0.41
Available-P (%)	0.05	0.39	0.39	0.39
Gnat body wt (g), mean[2]	1.95	2.60	2.20	2.29
Feeding activity[3]	2-1	2-3	1-1	1-2
Mortality (#fish)[4]	3	1	3	0
Bone ash (%), mean[5]	31.1	46.3	36.7**	33.9**
Bone ash (%), min[5]	25.5	43.3	28.8	26.7
Rib-def (F:S:N)[6]	2:4:0	0:0:6	0:4:2	3:2:1
Sp-def (F:S:N)[6]	3:3:0	0:0:6	0:1:5	2:1:3
Cara body wt (g), mean[2]	3.15	4.04	3.08	4.76
Feeding activity[3]	2-1	2-3	1-1	1-2
Mortality (#fish)[4]	0	1	0	0
Bone ash (%), mean[5]	39.4	50.1	48.6	43.6**
Bone ash (%), min[5]	36.5	48.3	44.5	38.9
Rib-def (F:S:N)[6]	1:2:3	0:2:4	0:2:4	2:4:0
Sp-def (F:S:N)[6]	0:0:6	0:0:6	0:0:6	0:1:5

[1-6] See footnotes of Table 1.

Experiment 3 (Effects of ferric chloride in a commercial diet):

Six test diets were prepared (Table 3). The basal diet (Diet 3a) was a commercial diet for common carp, containing 1.57% total P and 0.34% available P (based on *in vitro* analysis by Satoh et al., 1997). Diets 3b through 3f included either ferric chloride anhydrous ($FeCl_3$) or ferric ammonium citrate (Fe(III)NH_3-citrate; Fujifilm Wako Pure Chemical Co., Osaka, Japan) at levels of 2-4%. Other diet manufacturing protocols followed those in Experiment 1.

G. caerulescens (mean body weight 0.63 g) were stocked in 20-L aquaria (20 fish per tank, 1 tank per diet). The fish were fed their respective test diets for 30 days. *C. auratus* was not tested in Experiment 3, as this species was found to be less sensitive to dietary treatments based on the results of Experiments 1 and 2. Other rearing conditions and analytical methods followed those in Experiment 1. The mean values of the bone ash content were compared using Dunnett's test (Experiments 1-3), with significant differences determined at the 5% level.

Table 3 Diet composition (upper rows) and the composition of *Gnathopogon caerulescens* fed their respective diets (lower rows)

Diet	3a	3b	3c	3d	3e	3f
Commercial diet (g)	100	100	100	100	100	100
$FeCl_3$ anhydrous (g)	0	2	4	---	---	---
Fe(III)NH_3-citrate (g)	0	---	---	2	4	8
P-binding eq.[1]	---	0.38	0.77	0.19	0.39	0.78
Total-P (%)	1.57	1.57	1.57	1.57	1.57	1.57
Available-P (%)	0.34	0.34	0.34	0.34	0.34	0.34
Gnat body wt (g), mean[2]	2.07	2.00	1.80	2.31	2.47	2.02
Feeding activity[3]	3-2	2-2	2-1	3-3	3-3	3-3
Mortality (#fish)[4]	0	0	0	0	0	0
Bone ash (%), mean[5]	47.2	44.1	39.0**	44.3	43.1	44.1
Bone ash (%), min[5]	44.8	36.0	30.6	38.2	37.5	39.2
Rib-def (F:S:N)[6]	1:5:2	5:1:2	1:6:1	6:1:1	5:3:0	1:5:2
Sp-def (F:S:N)[6]	0:0:8	0:0:8	0:2:6	0:0:8	0:0:8	0:0:8

[1-6] See footnotes of Table 1.

Results

Experiment 1 (Ferric chloride does not decrease available P in a practical diet):

In the practical diet, supplemental ferric chloride up to 2% was apparently ineffective as a P-binder in reducing dietary P absorption in both species, as their bone ash content and the incidence of skeletal deformity were similar across dietary treatments (Table 1; Fig. 1-2). Despite the apparent ineffectiveness of supplemental ferric chloride, all dietary groups of fish exhibited clinically low bone ash content as well as bone deformities in ribs and spines (hemal and neural), especially at their growing ends. The types of bone deformities were similar among dietary treatments, with no instances of scoliosis or lordosis identified. *G. caerulescens* tended to have lower bone ash content and a higher incidence of bone deformities compared to *C. auratus*. Significantly higher bone ash content ($p<0.05$) was recorded in *C. auratus* fed Diet 1e. Dietary ferric chloride, up to 2%, did not appear to affect feed intake or mortality in the fish.

Experiment 2 (Ferric chloride decreases available P in a purified diet):

In the purified diet, supplemental ferric chloride at 2% reduced dietary P absorption in *G. caerulescens*, as indicated by bone ash content ($p<0.01$) and bone deformity (Table 2; Fig. 1-2). In *C. auratus*, the effect was less pronounced but still tended to reduce P absorption, with Diet 2d reducing bone ash content ($p<0.01$). Feeding activity was high in the P-supplemented diet (Diet 2b), whereas it was noticeably low in the P-deficient groups (Diet 2a, 2c, 2d), especially during the second half of the feeding duration. In *G. caerulescens*, bone deformity was prevalent in the P-deficient groups, whereas it was absent in the P-supplemented group. In *C. auratus*, a similar pattern was observed, although the response was less clear compared to *G. caerulescens*.

Experiment 3 (Ferric chloride decreases available P in a commercial diet):

In the commercial diet, supplemental ferric chloride up to 4% reduced bone ash content ($p<0.01$) and increased bone deformity in *G. caerulescens* (Table 3; Fig. 1). However, in the same diet, supplemental ferric ammonium citrate was less effective in decreasing bone ash content, with no significant reduction observed ($p>0.05$). Nonetheless, severe bone deformities, particularly rib deformities, were frequently recorded in this group of fish. Feed intake was higher in fish fed ferric ammonium citrate-supplemented diets compared to those fed ferric chloride-supplemented diets. The commercial diet itself was apparently deficient in available P content, as evidenced by the bone ash content and the occurrence of bone deformities.

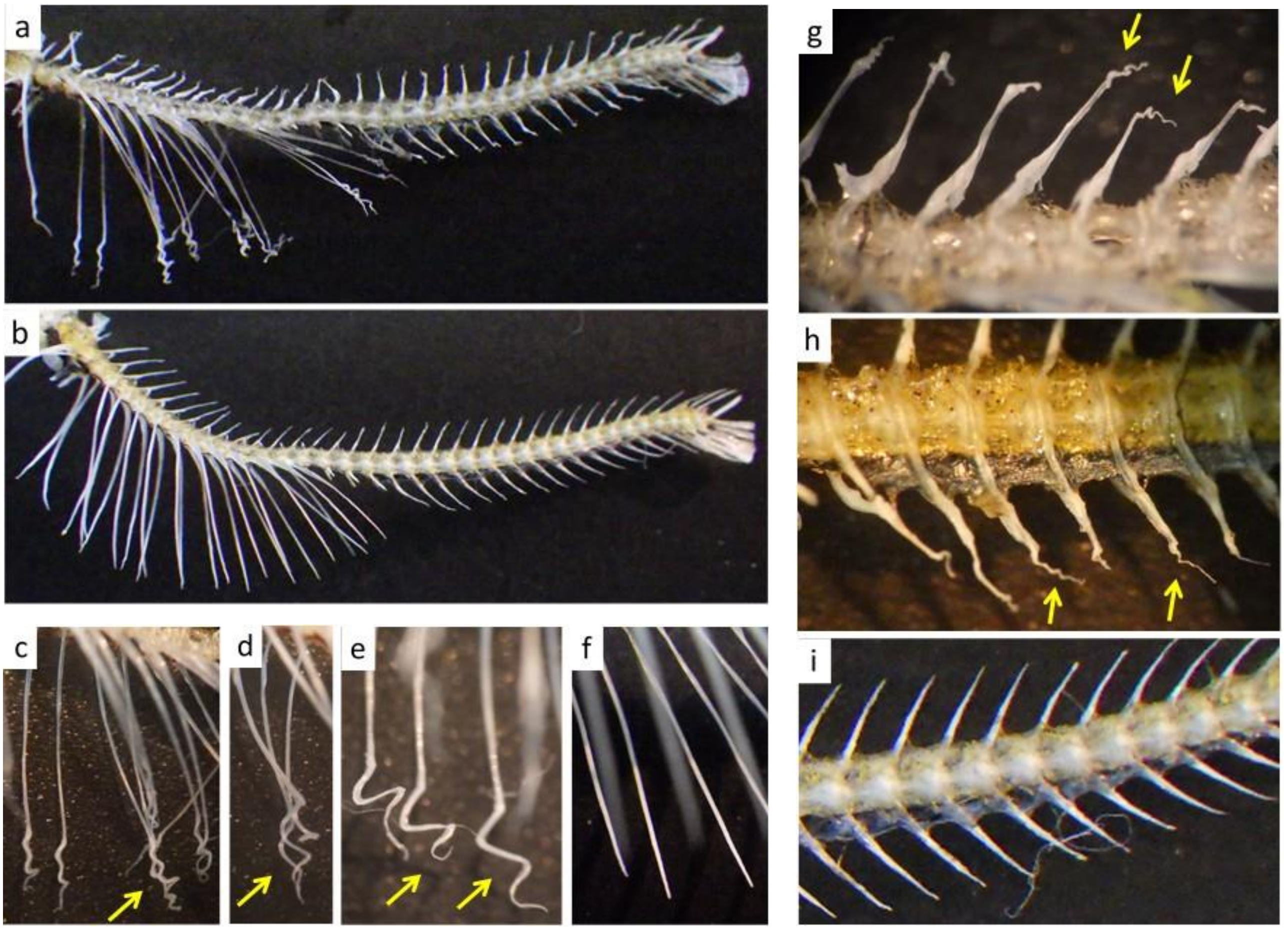

Figure 1. *Gnathopogon caerulescens*. (a) Skeleton of P-deficient fish fed Diet 1a, (b) Skeleton of normal fish fed Diet 2b, (c) Ribs of P-deficient fish fed Diet 1a: Yellow arrows indicate the wavy shape of the growing ends, (d) Ribs of P-deficient fish fed Diet 1b, (e) Ribs of P-deficient fish fed Diet 3d, (f) Ribs of normal fish fed Diet 2b, (g) Neural spines of P-deficient fish fed Diet 1e: Yellow arrows indicate the kinky shape of the growing ends, (h) Hemal spines of P-deficient fish fed Diet 3c, (i) Hemal and neural spines of normal fish fed Diet 2b (lint appeared accidentally at the bottom center).

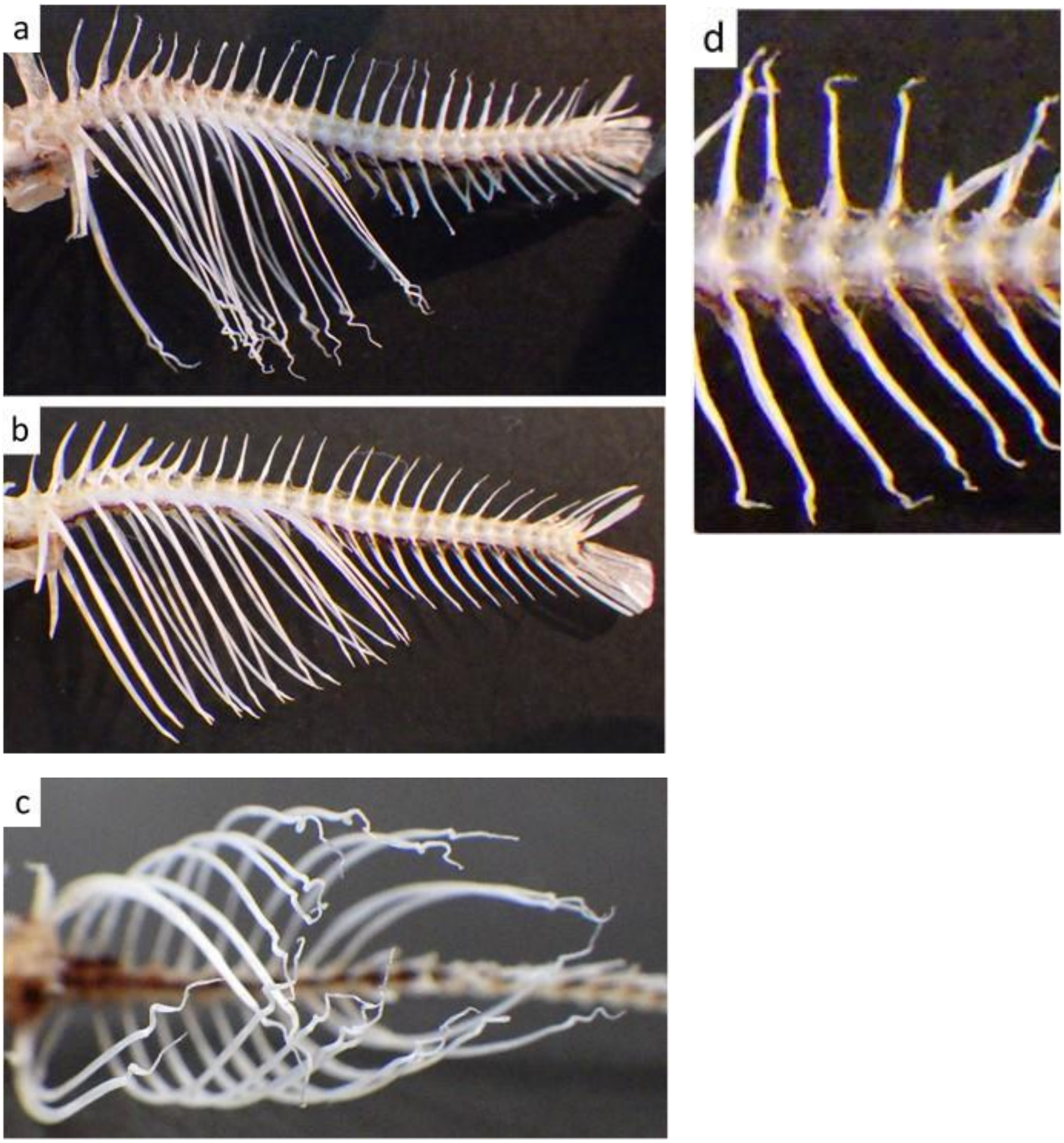

Figure 2. *Carassius auratus*. (a) Skeleton of P-deficient fish fed Diet 2d, (b) Skeleton of normal fish fed Diet 2b, (c) Ribs of P-deficient fish fed Diet 2d; ventral view: Note the wavy shape of the growing ends, (d) Hemal and neural spines of P-deficient fish fed Diet 1c: Note the kinky shape of the growing ends.

Discussion

As initially hypothesized, dietary supplementation of ferric chloride was expected to reduce dietary P absorption by fish and consequently reduce bone ash content. However, in Experiment 1, there was no apparent response in bone ash content to supplemental ferric chloride. The reason for this was unclear, but it was further hypothesized that the present diet (available P 0.17%) might contain little free inorganic P that could be bound or trapped by ferric ions. The diet, which contained 50% soybean meal, is known to contain various P compounds such as phytates, phosphoproteins, and phospholipids, but may contain little free inorganic P available to react with ferric chloride (Banaszkiewicz, 2011; Noack et al., 2012). To test this hypothesis, Experiment 2 was conducted using a semi-purified diet, where most of the P was present as a free inorganic form. In this diet, supplemental ferric chloride was highly effective in decreasing bone ash content, suggesting that ferric chloride reduced dietary P absorption by the fish. The response was more pronounced in *G. caerulescens* than in *C. auratus*, likely due to the size difference between the fish species (smaller fish generally respond faster to dietary treatments than larger fish). Fish fed Diet 2d, which contained vitamins instead of lard, had slightly lower bone ash content than those fed Diet 2c in both species. This could be attributed to enhanced growth rate (feed intake) resulting from the omission of lard and consequent increase in protein intake.

As evident from Table 2, the P-binding equivalent of Diets 2c and 2d was nearly equal to the available P content of the diets. Nonetheless, the bone ash content of fish in those dietary groups was higher than that of fish fed Diet 2a, indicating that portions of the available P (free inorganic P) in those diets were not bound to the supplemental ferric ions.

In a study with rats, Hsu et al. (1999) determined, based on *in vivo* P absorption data, the P-binding capacity of ferric ions (P bound per gram of Fe^{3+}), which was only 181 mg for ferric chloride and 101 mg for ferric ammonium citrate. This suggests that more than two-thirds of the supplemented ferric ions were not bound to P, indicating that substantially higher amounts of ferric ions would be required to trap most of the free inorganic P in the diet.

Researchers in sewage treatment technology also report detailed conditions for P removal, including optimum pH, concentrations of each reactant, and mixing intensity. They also indicate substantially higher Fe/P ratios for optimal removal of orthophosphates (Fytianos et al., 1998; Caravelli et al., 2010; Szabó et al., 2008).

Since Experiment 2 verified the effect of ferric chloride in trapping free inorganic P, Experiment 3 was conducted to confirm the P-binding effect of ferric ions using a commercial diet known to contain free inorganic P.

In the commercial diet, supplemental ferric chloride significantly decreased the bone ash content; however, the effect of ferric ammonium citrate was only moderate and statistically insignificant based on bone ash content. Despite this, fish fed ferric ammonium citrate showed a high rate of bone deformity, likely due to higher feeding activity (and thus higher growth rate), resulting in pronounced rib deformities especially at the growing ends. These deformities were similar to those reported previously in P-deficient salmonid species (Sugiura, 2018).

According to our previous data, the normal bone ash content of *G. caerulescens* of similar body sizes fed a P-sufficient diet was 52% (manuscript in preparation). Hence, in the present experiment, fish fed the basal commercial diet had notably lower bone ash content, suggesting that the basal commercial diet was insufficient in available P content. The low ash content was associated with bone deformities. Since the fish used in this experiment were small juvenile fish, the basal commercial diet, which was formulated for adult carp, must be insufficient in available P to support the rapid growth of juvenile fish that typically show better feed conversion compared to adult fish (Shearer, 1988; Eya and Lovell, 1997).

Although both ferric chloride and ferric ammonium citrate are commonly used as food additives for humans, the amount used as an iron source is much smaller than the amount required as a P-binder (Whittaker, 1998; Teucher et al., 2004). High dietary levels of ferric chloride could depress feed intake due to its highly acidic nature and chlorine-like smell (cf. The Merck Index). In Experiment 3, fish fed diets supplemented with ferric ammonium citrate showed noticeably higher feeding activity than those fed diets supplemented with ferric chloride, suggesting that ferric chloride might negatively affect feed palatability. In Experiment 1, the bone ash content was significantly higher in *C. auratus* fed Diet 1e compared to those fed the basal Diet 1a. This paradoxical result may not be incidental, as fish fed Diets 1c and 1d also exhibited higher bone ash content, although the differences were not statistically significant. This could also be linked to feed intake in fish fed Diet 1e, although daily observations did not detect any reduction in feed intake for these fish. In the rat study mentioned above, 4.4% $FeCl_3{\cdot}6H_2O$ (which is equivalent to 2.6% $FeCl_3$ anhydrous) or 5% ferric ammonium citrate was supplemented to their diet (Hsu et al., 1999). The rats well-accepted both diets, which is different from our present observation in fish. But, the authors also reported that ferric chloride was more potent than ferric ammonium citrate in lowering intestinal P absorption. This is in agreement with our present study.

Conclusion

For commercial or farm-made feeds containing an excess amount of available P, supplementation with ferric iron can reduce the available P in the diet and consequently reduce the soluble P excretion into the environment. Since large fish consume most feed in commercial aquaculture, and since large fish require significantly less P in their diet compared to small juvenile fish, adjusting the dietary available P content could help protect the aquatic environment surrounding fish farms. When reducing dietary available P content using P-binders, occasional monitoring of the bone ash content (bone density) of cultured fish is recommended to safeguard against clinical P deficiency. Early P deficiency can also result in rib deformities at their growing ends, with similar deformities observed in the neural and hemal spines. Scoliosis or lordosis of the vertebral column may be absent except in cases of extreme P deficiency. P-deficient fish may appear externally normal even under severe P deficiency.

Ethical statement

The author declares that the present study was conducted in accordance with the guidelines approved by the Field-Experiment Committee of the University of Shiga Prefecture.

Informed consent

Not available

Conflicts of interest

There is no conflict of interests for publishing of this study.

Data availability statement

The author declares that data are available from the author upon reasonable request.

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RESEARCH PAPER

Empowering Hilsa Heroines: Unveiling Gender, Socioeconomic Dynamics, and Environmental Influence in Bangladesh's Hilsa Fisherwomen Community

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Abstract

This study provides a detailed insight into the socioeconomic challenges faced by fisherwomen households in the Shugondha riverbank Hilsa fishing community of Bangladesh. Despite their active involvement in hilsa fishery, these households grapple with various economic and social hurdles. The research methodology, employing a mix of questionnaire interviews, focus group discussions, cross-check interviews, and secondary data collection, ensures a comprehensive understanding of the subject. Conducted over 12 months in Chandkathi Jelepara, Jhalokathi Sadar Upazila, Jhalokathi district, the analysis included 42 households with 100 active fishers, sustaining 240 people. They are predominantly Hindu and illiterate (52%), socio economically poor households (57%), and lacking land ownership (90.5%) and basic amenities. Food shortages during fishing bans were managed through reduced meals and cheaper goods. Limited control over household income (2%) and low awareness of rights (95%) were observed among fisherwomen. Income generation efforts were hindered by resource scarcity and lack of skills. However, 10% recognized the need for diversifying income sources and active participation in community initiatives. Vulnerability was high, emphasizing the need for support from government, NGOs, and other organizations to improve livelihoods, particularly through alternative income options.

Introduction

Hilsa (*Tenualosa ilisha*, Hamilton 1822), revered as the "king of fishes" and Bangladesh's national fish, holds pivotal significance in the nation's economy, employment landscape, export earnings, and food supply (Haldar et al., 2004; Rahman, 2006; Roy et al., 2015). Renowned for its nutritional value, taste, and market demand, Hilsa has become a symbol of pride for Bangladesh, contributing significantly to its fish production and GDP (Gross Domestic Product) (DoF, 2015; FRSS, 2016). Despite its economic importance, the hilsa fishing community faces myriad challenges, including habitat degradation and overfishing (Mozumder et al., 2020). Government-imposed bans on juvenile and gravid hilsa fishing aim to safeguard the species' sustainability, albeit with varying impacts on the livelihoods of fishing communities, who face poverty and social neglect (Islam et al., 2016). Despite increased hilsa production, poverty persists among fishing households, exacerbated by limited alternative livelihood options during fishing bans (Sharker et al., 2015). In Bangladesh, women, constituting half of the population, confront significant challenges including economic dependency, educational disparities, and social marginalization (Sultana et al., 2010). Despite their pivotal roles in various sectors, gender discrepancies persist across health, employment, asset control, and decision-making, thereby impeding women's empowerment and socioeconomic progress (Sultana and Hasan, 2010; Sarker and Rahman, 2007; Hoque and Itohara, 2008). Particularly in small-scale fisheries, women's substantial contributions often go unrecognized in policy formulations (Pauly, 2006; Engelman et al., 2009; Sharma, 2011). Nevertheless, their contributions in bolstering community resilience and mitigating vulnerability remain paramount (Engelman et al., 2009; Chen, 2000; Kebe, 2009). The extent of women's participation is influenced by regional disparities, societal and cultural norms, and technological factors (Clayton and Savage, 1974). Notably, women gravitate towards activities requiring minimal investment while still contributing significantly to household incomes (Francis, 1995; Ogutu, 1988; Medard and Wilson, 1996).

Despite the vulnerability of fishing communities and the pressing need for targeted interventions, comprehensive studies focusing on hilsa fisherwomen in Bangladesh are notably lacking (Nandi & Parmanik, 1994; Shankar, 2010; Saxena et al., 2014). Understanding their socioeconomic conditions is essential for effective policy formulation and program implementation (Hossain et al., 2022; Ofuoku et al., 2008). Existing research on fishing communities' status underscores the urgency of addressing their challenges to improve livelihoods and alleviate poverty. This study aims to fill this gap by examining the socioeconomic dynamics of hilsa fisherwomen, shedding light on their experiences, challenges, and contributions to the fishery sector. By elucidating their roles and constraints, this research seeks to inform policymakers and stakeholders, facilitating informed decision-making and holistic interventions to uplift the livelihoods of hilsa fisherwomen in Bangladesh.

Materials and Methods

Study Site

Chandkathi Jelepara, located at 22°38′24″N/90°12′21″E, adjacent to the Shugondha River and the Gurudham Canal, served as the study's focal point. Situated within Jhalokathi Sadar Upazila of the Jhalokathi district, the community falls under the governance of Jhalokathi Pouroshova, Ward 3 [Figure 1 (a&b)].The selection of Chandkathi Jelepara as the study's focal community is justified by several key factors. Firstly, the absence of cultural barriers enables Hindu women to actively engage in field-oriented work, facilitating comprehensive data collection and insights into their socioeconomic conditions. Additionally, the community boasts a high concentration of Hilsa fishers, aligning closely with the study's focus on hilsa fishing communities. This alignment ensures that the study objectives resonate with the community's interests and needs, enhancing the relevance and applicability of the findings. Furthermore, Chandkathi Jelepara benefits from an established communication infrastructure, facilitating efficient data collection and stakeholder engagement. Its proximity to the river's embankment further enhances accessibility and relevance to the study, considering the community's reliance on river-based livelihoods. Moreover, the predominance of professional and ancestral fishermen within the community ensures a rich and nuanced understanding of the socioeconomic dynamics at play, contributing to the depth and breadth of the study's findings.

The study spanned 12 months, from January to December 2019, to capture comprehensive insights into the socioeconomic landscape of Bangladeshi fisherwomen in the Hilsa fishing community.

Data Collection

Structured interview schedules were crafted to systematically collect data on various aspects including household demographics, literacy, health, water and sanitation, land ownership, occupation, income, economic and nutritional status, gender dynamics, women's mobility, vulnerability and resilience, as well as the environmental impact of existing socioeconomic conditions.

Data collection involved a multifaceted approach to capture comprehensive insights into the socioeconomic dynamics of hilsa fisherwomen. Firstly, comprehensive surveys were conducted through questionnaire interviews (QI) in all 42 fisherwomen households within the study area, providing detailed information on various socioeconomic indicators. Additionally, Focus Group Discussions (FGD) were conducted using Participatory Rural Appraisal (PRA) techniques, engaging both fishermen and fisherwomen to delve into topics such as gender roles, alternative income sources, and the impact of fishing bans on household nutrition and resilience. Cross-check interviews (CI) with key stakeholders, including the Upazila Fisheries Officer (UFO), NGO representatives, and local government officials, were conducted to validate and complement the findings from household surveys and FGDs. Furthermore, supplementary data were gathered through secondary sources such as literature reviews, online sources, research papers, and publications, enriching the analysis with additional insights and perspectives. This comprehensive approach ensured a holistic understanding of the socioeconomic conditions and challenges faced by hilsa fisherwomen in the study area.

Data Processing, Analysis, and Presentation

Collected data underwent meticulous scrutiny and tabulation, with MS Excel 2010 employed for processing and analysis. Results were presented through categorized tables and figures, with a percentage analysis facilitating clear insights. The study report underwent drafting and finalization phases to ensure accuracy and clarity.

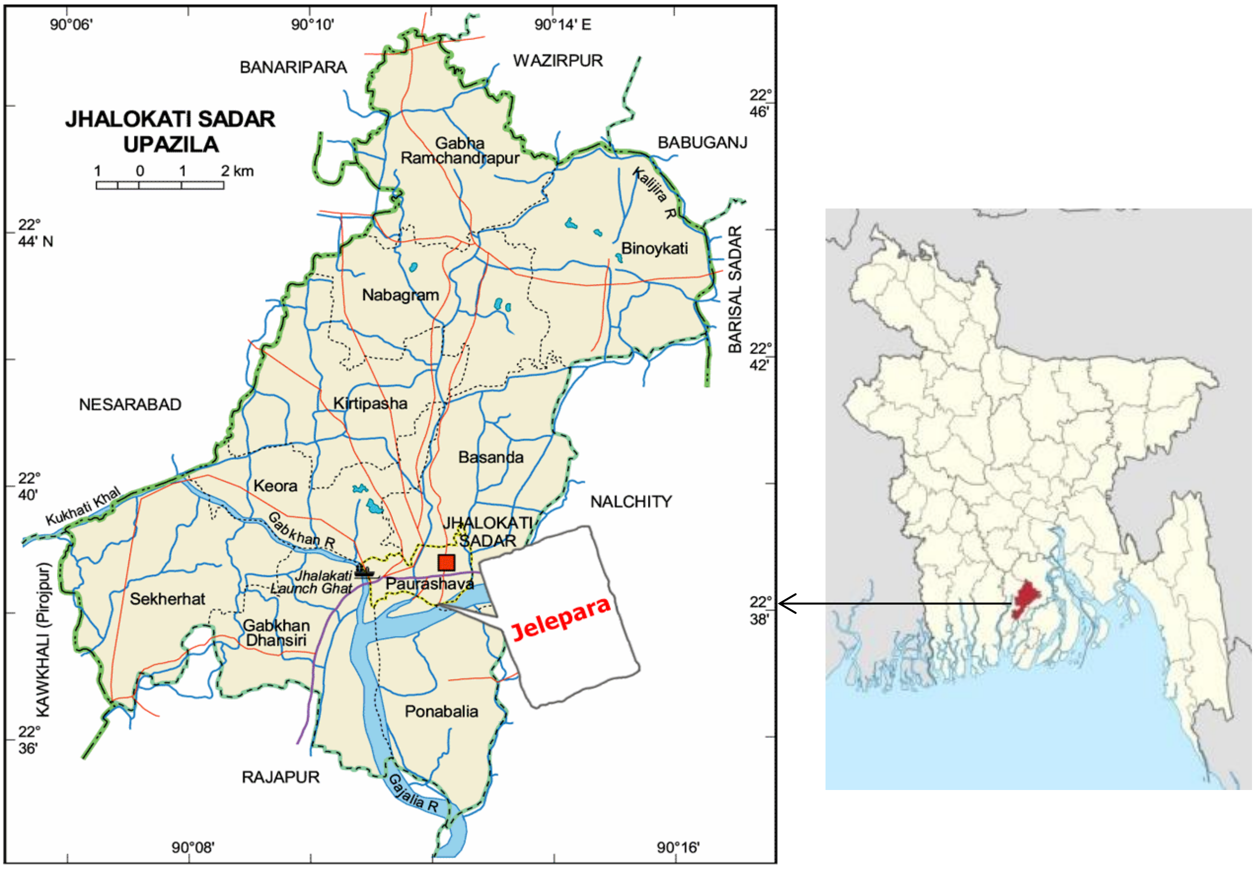

Figure 1(a): Map showing the location of Chandkathi Jelepara fishing community within the Jhalokathi district of Bangladesh

Figure 1(b). Map displaying the study location with precise GPS coordinates.

Results and Discussions

History of the Community

Three and a half decades ago, seven fishermen households initially settled in that location after losing their homes to Shugondha River's erosion. Over the years, more families joined them, forming a community of traditional fishermen, all from the same caste. Now comprising 42 households, their livelihood depends solely on hilsa fishing. Despite their daily struggles, they continue to reside on temple property, lacking their own homes and paying rent by constructing small sheds.

Social profile of the community

Chandkathi Jelepara, a pivotal hilsa fishing enclave, comprises 42 households housing 100 active male fishers, supporting approximately 240 individuals. The male-to-female ratio stands at 60:40, with the community exclusively depending on fishing for sustenance. Notably, owing to religious customs, no female fishers are present, and the practice of river fishing entails labor-intensive efforts. All households share a Hindu identity and belong to the same caste, with fishing serving as the exclusive and enduring source of income for successive generations. This underscores the community's distinct social and economic reliance on hilsa fishing.

Age structure of fisherwomen

The study revealed that 36% of the fisherwomen were under 20 years old, 40% were in the 20–40 age range, 17% were between 40–60 years old, and only 7% were over 60 years old (Figure 2). Age distribution among fisherwomen varies significantly across different studies and regions. Bhargav et al. (2020) observed a predominance of middle-aged women (31–56 years) in fisher communities, while Mary et al. (2015) found that most mussel fishers in Kanyakumari District were aged 40–60 years. Kalita et al. (2015) noted a significant number of fishermen aged 31–50 years in Barpeta, Assam, whereas Hossain et al. (2022) highlighted a shift towards younger demographics, with many in the 18–30 age group. Other studies, such as Rana et al. (2018), Minar et al. (2012), and Ali et al. (2009), consistently reported a prevalence of fishers aged 31–40 years. Ahmed et al. (2021) also emphasized a large proportion aged 26–30 years. In the Sundarbans, Bhaumik and Saha (1994) documented a broader age range (20–70 years), while Sheikh and Goswami (2013) reported that most respondents in the Chandakhola wetland of Dhubri, Assam, were aged 31–50 years.

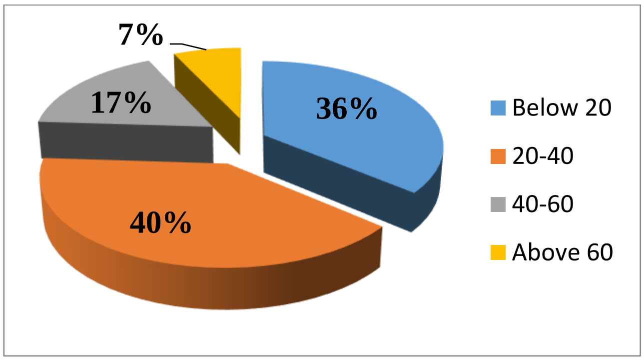

Figure 2. Age Structure of Fisherwomen in Chandkathi Jelepara fishing community (Percentage)

Family size and Type

In this study, 48% of households had ≤5 family members, 28% had 6-8 members, and 24% had more than 8 members (Figure 3). The study findings on the family size of fisherwoman households reveal a diverse range across various research efforts. Similarly, Bhargav et al. (2020) reported that 48.7% of respondents had ≤5 family members, while Ali et al. (2009) found a majority of families with less than 5 members. Shankar (2010) and Anon (2005) reported varying percentages of families with 5 members, while Mary et al. (2015) noted a distribution of fishermen families across different size categories, with the majority having 2-4 members. These findings highlight the diversity in family size among fishing communities, influenced by regional, socioeconomic, and cultural factors. In contrast, Hossain et al. (2022) observed that 80% of fishermen had 5-8 family members. Comparisons with national averages (4.0 people per family), as highlighted by the Population & Housing Census 2022, reveal that hilsa fishing communities tend to have larger family sizes.

The study also revealed that nearly all households within the fishing community were joint families, a situation attributed to landlessness leading to shared housing arrangements despite distinct living setups and economic activities. This contrasts sharply with recent findings by Hossain et al. (2023), where a significant majority of fishermen were found to belong to nuclear families. The discrepancy is notable, especially when compared to earlier research by Hossain et al. (2022), which reported a predominant prevalence of single-family households among fishermen. Similarly, Ahmed et al. (2021) identified a preference for nuclear family structures among Hilsa fishers in the Meghna River Estuary, diverging from the joint family dynamics observed in this study. However, our results closely resemble those of Rana et al. (2018) and Minar et al. (2012), who also documented a high prevalence of joint family setups among fishermen, highlighting the complexity and variability in household structures within fishing communities.

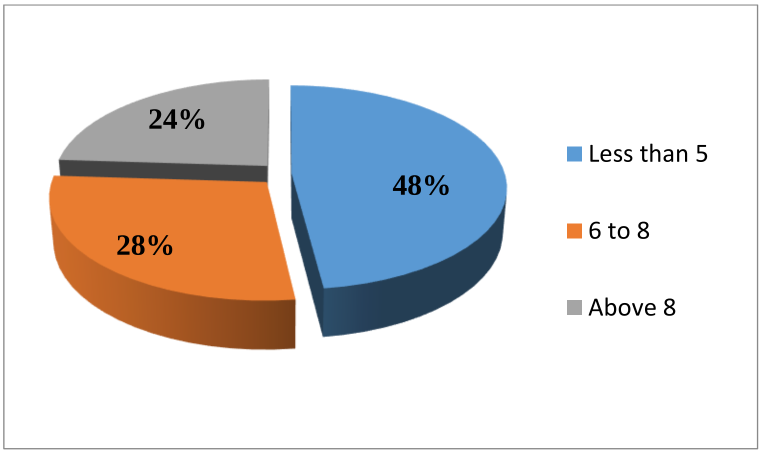

Figure 3. Percentage of Family Size (Members) in Fisherwomen Households in Chandkathi Jelepara fishing community

Literacy rate of fisherwomen

The majority (52%) of the fisherwoman households were illiterate, followed by 41% were able to sign only, and the remaining 7% had the primary level of education (Figure 4). It is due to the lack of awareness about education as they were born into professional fishing families as well as the poor economic status of their parents. The study findings underscore a significant disparity between the literacy rate among fishing communities and the national average of 75.2% (Bangladesh Economic Review, 2020), with a notably lower literacy rate observed among fisherwomen. In a similar study by Bhargav et al. (2020), it was revealed that the majority of fisherwomen (88.1%) were illiterate. This pattern aligns with earlier research by Mohinigadhia et al. (1999), Shahjahan et al. (2001), Sheikh and Goswami (2013), Kalita et al. (2015), Saxena (2014), Bhuyan and Islam (2016), and Mary et al. (2015), which reported varying degrees of illiteracy among fishermen, ranging from 55% to 80%, across different regions in Bangladesh and India.

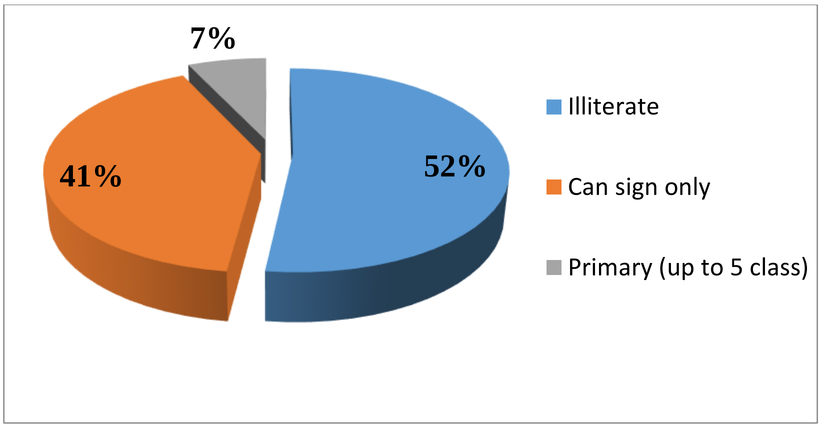

Figure 4. Percentage of Literacy rate of fisherwomen in Chandkathi Jelepara fishing community

Health facility

The study found that all fisherwoman households had access to healthcare through the nearby Upazila Sadar hospital. However, broader healthcare access challenges were evident, with the Bangladesh Economic Review 2020 indicating a low ratio of one registered physician for every 1724 people. Hossain et al. (2023) also noted significant limitations in healthcare access in Meghna riverbank fishing communities, where the number of people per doctor might exceed several thousand, highlighting the need for improved healthcare infrastructure in such areas.

Water, sanitation and hygiene status

In this study, the fishing community relied on four shallow tube-wells for drinking water, while river water served other purposes, although interruptions sometimes necessitated using river water for drinking. This contrasts with the national analysis reported in the Bangladesh Economic Review 2020, where 98.3% of the population has access to clean water. According to the investigation, it was revealed that sanitation facilities in this community were limited, with only four brick sanitary latrines provided by the government, leading community members to share facilities with neighbors for health purposes, posing significant challenges and ultimately resulting in them having no choice but to use the river bank as a toilet. Moreover, just 10% of households had ring slab latrines, highlighting significant disparities compared to the national average of 81.5% access to improved sanitation facilities, as mentioned in the Bangladesh Economic Review 2020. These disparities reflect the specific challenges faced by the fishing community, particularly due to their landless status and economic constraints.

Traditional knowledge

It was observed that women were engaged in domestic activities and were not allowed to go out fishing due to social and security problems. They have traditional knowledge of net mending and different types of fishing trap making. And they can catch fish by hook and line (Chip borshi, Chara borshi) and using the cast net. Hossain (2021) and Hossain et al. (2022) uncovered a wealth of traditional knowledge within fishing communities pertaining to fish catching techniques, including chai fishing, zag fishing, and others. When the fish catch was abundant, they used to conduct several methods of fish processing, such as fish drying and lona ilish (salted hilsa). The findings of this study coincide with those of Hossain et al. (2019), and Hossain et al. (2022), who observed that nona ilish (salted hilsa) and fish drying were prevalent practices within the hilsa fishing community. Additionally, Jeyaram et al. (2009) found, in their examination of traditional fermented foods in Manipur, that salting, drying, and smoking fish were the primary methods of preservation in this region of India.

Livestock status

This investigation discovered that livestock ownership among fisherwoman households is minimal, with only 16.5% keeping animals on a small scale, primarily chickens, ducks, pigeons, and goats, while the majority (84.5%) were not engaged (Figure 5) due to constraints such as lack of rearing facilities, high mortality rates, and insufficient technical knowledge. This echoes recent findings by Hossain et al. (2023), where only 9.33% of riverbank fishermen own livestock, primarily due to similar challenges. Additionally, an earlier study by Hossain et al. (2022) reported that just 3% of families in the fishing community of Bangladesh's Chandpur region had animals, highlighting the need for improved access to rearing facilities and technical knowledge through collaboration with local service providers.

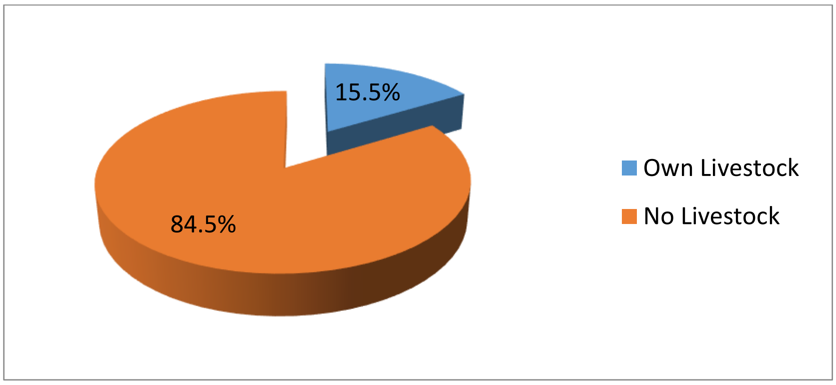

Figure 5. Percentage Livestock Status in Fisherwomen Household in Chandkathi Jelepara fishing community

Land holding, Housing and infrastructure

The study findings revealed that the vast majority (90.5%) of fisherwomen households were landless (Figure 6), residing in makeshift tin shed houses on temple land for a monthly fee of 150–200 BDT (Bangladesh Taka), while only 9.5% owned medium tin shed houses on their own land, primarily due to the community's vulnerable location on the river embankment. No households owned agricultural land. In a recent study by Hossain et al. (2023), it was found that 56.67% of fishermen were landless due to river soil erosion, with 40.00% having only homestead land and 3.33% owning both homestead and agricultural land, highlighting their vulnerability to natural disasters. Ahmed et al. (2021) observed that 57% of fishermen had no land, while 33% had 5 to 10 decimals and 10% had more than 10 decimals, with the majority residing in tin and wood houses (53%) and the rest in dwellings with straw roofs and bamboo fences (24%), semi-pacca (18%), and pacca (5%). Additionally, Hossain et al. (2022) noted that 60% of households lived in tiny tin-shed homes and 40% in medium tin-shed homes, with only 40% owning their own homesteads and the rest relying on rented land or homes. Minar et al. (2012) reported that 66% of fishermen's households had bamboo and tin-shed houses, while 24% had tin-shed walls. Furthermore, studies by Faruque and Ahsan (2014) and Alam and Bashar (1995) noted that the majority of fishermen's households had kacha housing structures.

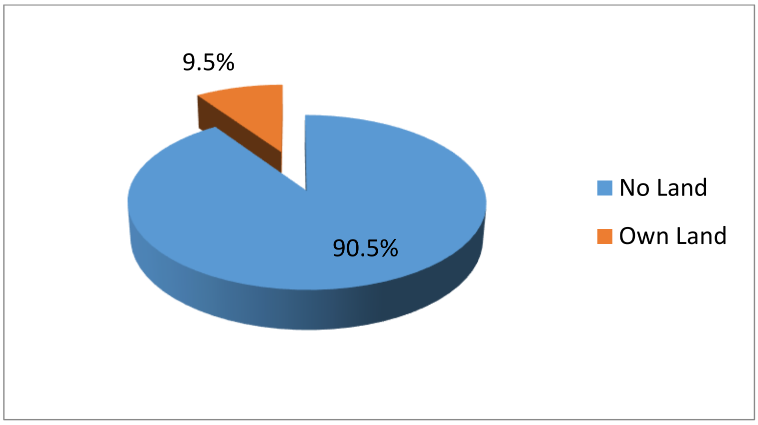

Figure 6. Percentage of Land Holding Status of Fisherwomen Household in Chandkathi Jelepara fishing community

Another discovery made during the investigation is that the road communication was excellent due to the community's urban location, with most roads being paved. These well-maintained roads were easily accessible to rickshaws, vans, and motorized vehicles, facilitating the transportation of input supplies to local and distant markets for product marketing within a reasonable distance. Consequently, fishers enjoyed convenient access to these facilities.

Economic status of Fisherwomen Household

The majority of households in the studied community live in poverty, experiencing societal marginalization and lacking access to land. The study revealed that 57% of households were extremely poor, followed by 34% classified as poor, and an additional 9% categorized as moderately poor (Figure 7). This study derives its poverty estimation from tangible assets, income, and expenditure. According to the FGDs, the average monthly income of households was lower than their average monthly expenditure. This finding indicates significantly lower income levels compared to those reported in the Bangladesh Economic Review (2020), which estimated the average monthly income for an individual at 14,574 BDT. In contrast to Hossain et al. (2023), where 56.67% of fishermen were extremely poor, 23.33% poor, and 20.00% moderately poor. Another earlier study by Hossain et al. (2022) found 60% extremely poor, 20% destitute and 20% moderately poor, with inadequate incomes to cover expenses.

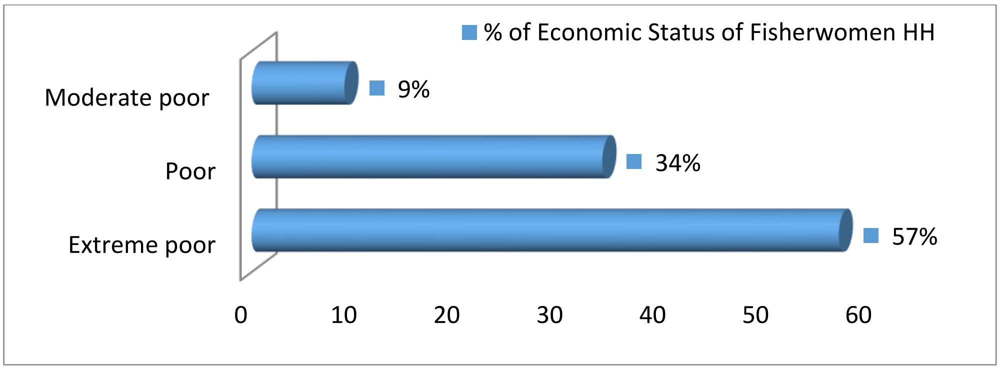

Figure 7. Economic status of Fisherwomen Household in Percentage

Nutritional Status:

Fisherwomen households endure significant hardship throughout the year to meet their basic needs, particularly during fishing bans when food shortages are prevalent. While some manage by reducing meal frequency and opting for cheaper alternatives, many struggle to make ends meet. Despite being involved in fishing, households often lack access to fish due to selling it for cash, relying instead on vegetables for sustenance. Occasional access to eggs or meat is considered fortunate. Dietary differences between fishing and ban seasons are highlighted in Table 1.

Table 1. Diets of Fisherwomen Households during Fishing and Ban Seasons

Food Items	Fishing Season	Ban Season
Rice	Daily	Daily
Fish	5-6 days/week	1-2 days/week
Vegetables	4-5 days/week	6-7 days/week
Meat/Egg/Milk	Once or twice/month	Rarely

Amidst fishing bans, fisherwomen within households experience a dire scarcity of protein intake, partaking in such nourishment exceedingly rarely due to prevailing food shortages. The nutritional challenges faced by fisherwomen stem not only from poverty but also from socio-cultural biases against women, perpetuating misconceptions and taboos surrounding food habits. Gender discrimination, especially prevalent in regions like Sundarban, exacerbates these issues, as observed by various studies (Anonymous, 1997; Roy et al., 2013; Basu, 2011).

Gender dynamics of the fishing community

In the study area, gender dynamics exhibit a significant imbalance, with women facing under-representation in cooperatives, limiting their access to economic power and support. Traditional gender roles persist, relegating women to household duties without recognition for their workload. Fisherwomen encounter a lack of decision-making power, with only 2% able to make independent decisions. This extends to financial matters, as women have nominal control over household income, resources, and loan utilization (Table 2).

Table 2. Gender dynamics in the fishing community

Issue	Current Situation
Workloads and gender division of labour	Women in the community conform to traditional gender roles, with responsibilities primarily centered around family care, household work, and child-rearing.
Decision Making power in HH and community level	Decision-making power predominantly lies with males in the family, with 70% of decisions made solely by men. Only 2% of women can take decisions independently.
Access to Income and expenditure	Husbands primarily influence spending decisions, although expenditures are mutually discussed. The earning member, usually the husband, plays a significant role.
Access to Loan (Micro-credit)	Women secure loans from NGOs but face limitations in independent spending due to male control over loan reimbursement.
Control over Income	Men control about 95% of the household income.
Control over Household Asset	Approximately 90% of household assets are under male control, influencing decisions regarding asset buying or selling.
Legal rights & Status (e.g., ownership of Land)	Women in the community are largely unaware of legal rights over assets, with 95% having limited knowledge in this regard.
Access to Education of female children	Joint decision-making on female children's education is prevalent, with girls receiving preference due to government-sponsored education up to class eight.
Family Planning	Collaborative decision-making on family planning, with men having a greater influence.
Health Care	Women can access health care with the permission of a male family member.
Gender-based Constraints	Social prejudice, lack of education, and social negligence towards women, hindering higher education.
Gender-based Opportunities	Efforts to create opportunities for women, including involvement in alternative income-generating activities, skill development, and leadership training.

Mobility of fisherwomen

The study revealed that fisherwomen in the community have limited mobility outside their homes, typically covering distances ranging from 0.25 to 2.0 kilometers. Their outings are often brief, with family members or relatives accompanying them when necessary. The survey identified 14 distinct destinations frequented by fisherwomen, as outlined in Table 3.

Their movements are typically sanctioned by their husbands, particularly as the men engage in daily fishing activities. Interestingly, even routine trips, such as visiting neighbors, often require approval from their husbands to maintain familial harmony. Notably, only 10% of comparatively younger fisherwomen display frequent mobility beyond the community, while 50% move occasionally, and 40%—comparatively older individuals—rarely venture beyond attending religious festivals or visiting close relatives.

Table 3. Fisherwomen Mobility of Chandkathi Jelepara

SL	Destination	Purpose	Accompanied by	Distance (km)	Permission Required
1	Primary School	School admissions, book collection, stipends	Children, neighbors	0.25	Yes
2	Social Welfare Office	Old age allowance, benefits for children	Children, neighbors	1.0	Yes
3	NGO/MFI	Loans, payments, installments	Husband	0.5	Yes
4	Upazila Parishad	Healthcare, family planning, VGF	Husband, neighbors	1.0	Yes
5	Pouroshova	Sewing training, birth certificates	Neighbor	0.5	Yes
6	Sadar Hospital	Medical treatment	Husband, neighbor	0.5	Yes
7	Pharmacy	Medication purchases	Children	0.25	Yes
8	Temple	Worship	Family, neighbor	Within community	Yes
9	Religious Festival	Observance of religious festivals	Family, neighbor	2.0	Yes
10	Boro Bazar (Big Market)	Tailoring training, shopping	Alone, neighbor	1.0	Yes
11	Riverbank Park	Recreation	Kin	0.25	Yes
12	Kheya Ghat	Cross-river travel	Family	0.25	Yes
13	Market	Shopping	Family, neighbor	1.0	Yes
14	Father's House	Visits	Family, children		Yes

Occupation and Income of Fisherwomen

In the examined fishing community, traditional gender roles dictate that fisherwomen primarily engage in domestic tasks, while men are the primary breadwinners through fishing activities. However, environmental challenges such as declining fish stocks and the impact of climate change are compelling hilsa fisherwomen to seek alternative income sources. Studies by Haque and Itohara (2009), Haque and Yamao (2009), Mondal et al. (2009), and Panda (2009) emphasize the importance of tailored interventions for gender-inclusive economic growth in coastal communities.

Despite facing challenges like limited resources and skills, fisherwomen are resiliently participating in Additional Income Generating Activities (AIGAs), including small-scale livestock rearing (e.g., poultry, pigeon, duck, and goat rearing) and income-generating tasks such as net mending, Katha stitching, and tailoring. However, obstacles such as technical knowledge gaps and high livestock mortality rates hinder their effectiveness. Younger fisherwomen actively seek training to enhance their tailoring abilities, reflecting a proactive stance toward economic empowerment. Nevertheless, it is essential to address challenges such as the high cost of sewing machines and the need for ongoing technical support to ensure the sustainability of this income source. Studies by Hasan et al. (2015) highlight rural women's engagement in various agricultural and non-agricultural activities to support their households.

Moving forward, the community is exploring various potential Additional Income Generating Activities (AIGAs) to further diversify income streams and enhance household resilience.

Initiatives such as paper packet making, grocery shopping bag production, and handicraft production are being considered due to their environmental sustainability and market demand. Similarly, ventures like breeding buck rearing and high-quality pigeon rearing show promise for sustainable income generation, although initial support and technical knowledge are necessary. Furthermore, endeavors like mushroom cultivation and cage culture in canals offer secure income sources, while dry food processing and small-scale trade provide avenues for regular income. These efforts underscore the community's dedication to exploring diverse income opportunities for long-term economic stability and growth, aligning with studies conducted by Hoque and Itohara (2009), Haque and Yamao (2009), Mondal et al. (2009), and Panda (2009).

Vulnerability and Resilience

The vulnerabilities faced by fisherwoman households within this community are multifaceted, encompassing social, economic, and climatic factors, each posing significant threats to their livelihoods. Social vulnerabilities, such as dowry demands during marriages, early marriages resulting in increased workload and health risks for young brides, and the stigma of financial insolvency, contribute to immense pressure on these households. Additionally, economic vulnerabilities manifest during fishing bans, leading to insufficient income, reduced access to education and healthcare, and heightened household tensions. The lack of Alternative Income Generating Activities (AIGAs) exacerbates economic instability, prompting seasonal migration and even illegal activities to cope with financial constraints. Climatic vulnerabilities, including cyclones and land erosion, disrupt fishing activities, result in loss of income and property, and exacerbate health risks due to unsafe drinking water and waterborne diseases.

In response to these challenges, fisherwoman households employ various coping strategies to mitigate the impacts of vulnerabilities. Financial coping mechanisms involve borrowing loans from NGOs, local lenders, or relatives, selling fishing gear, and reducing meal frequencies to manage expenses. Social coping strategies include raising awareness against dowry and early marriage, enforcing regulations to prevent child marriage, and advocating for suitable AIGAs to alleviate economic stress. Moreover, efforts are made to adapt to climatic vulnerabilities by investing in safe drinking water facilities, implementing protective measures against land erosion, and seeking refuge on embankments or migrating to safer locations.

Despite these coping mechanisms, vulnerabilities persist and continue to undermine the resilience of fisherwoman households. Sustainable solutions necessitate comprehensive approaches that address the root causes of vulnerabilities, including gender-based discrimination, economic disparities, and environmental degradation. Empowering fisherwomen through education, skill development, and access to resources can enhance their capacity to withstand shocks and build resilience within their communities. Additionally, collaborative efforts involving government agencies, NGOs, and community stakeholders are essential to implement effective interventions that promote sustainable livelihoods and enhance the overall well-being of fisherwoman households.

Vulnerabilities faced by fisherwoman households in a community, supported by scientific references from relevant studies. Studies by Islam et al. (2016) and Porras et al. (2017a) identify challenges such as improper implementation of bans and limited access to resources. Market disruptions are a prominent shock, affecting small-scale fishers' economic survival (Bennett et al., 2020). Diversifying income sources is a key resilience strategy, though some households struggle due to low income and limited access to credit (Islam et al., 2014). Challenges also arise from the informal money lending system, affecting community cohesion (Choudhury et al., 2021). Limited participation in formal institutions hampers community resilience (Berkes and Ross, 2013). Government initiatives offer limited relief, with exclusion from compensation packages exacerbating social divisions (Mozumder et al., 2020). Inclusive policies are needed to enhance resilience without perpetuating social stratification (Dewhurst-Richman et al., 2016). Household resilience varies, with a need to address negative interactions at the community level (Islam et al., 2020a). While fishing remains a primary occupation, adaptation strategies are evolving, with potential for transformation in the future (Islam et al., 2021a).

Effect on environment of existing socioeconomic condition

The impoverished socioeconomic conditions among fishermen have significant environmental repercussions, manifesting in unsustainable fishing practices, habitat degradation, and depleted fish stocks. Economic hardships often force fishermen into practices that harm the environment, such as overfishing and using illegal gear. Without sufficient financial resources, they struggle to adopt sustainable practices, and the lack of education exacerbates this issue by limiting awareness of the long-term benefits of conservation. These challenges lead to severe environmental consequences. Continuous exploitation of natural resources degrades fish habitats, including rivers, canals, and floodplains, reducing biodiversity and threatening the viability of the fishing industry. Overfishing, driven by the need to meet immediate economic needs, has led to a significant decline in fish stocks, jeopardizing food security and livelihoods. Additionally, inadequate sanitation practices contribute to water contamination and the spread of infectious diseases. The discharge of night soil into water bodies fosters vector-borne diseases, posing public health risks and further straining the community.

To address these issues, several potential solutions and community-driven initiatives can be implemented. Education and awareness programs focused on sustainable fishing and environmental conservation can empower fishermen to make informed decisions. Financial support through microloans or subsidies can help them transition to sustainable practices, such as using environmentally friendly fishing gear. Community empowerment programs can foster local leadership in conservation efforts, while targeted interventions to improve sanitation infrastructure, such as providing low-cost latrine pans, can reduce water contamination and disease spread. Encouraging sustainable fishing practices, such as seasonal fishing bans and the establishment of fish sanctuaries, can help restore fish stocks and protect habitats. Local conservation efforts, like reforesting riverbanks and protecting breeding grounds, are crucial for ecosystem restoration, with community involvement ensuring long-term investment in environmental health.

By addressing these socioeconomic challenges and promoting sustainable practices, fishing communities can build resilience and protect their environmental resources. These initiatives not only safeguard livelihoods but also ensure the health and sustainability of the ecosystem for future generations.

Conclusion

The socioeconomic and livelihood characteristics of hilsa fisherwomen reveal significant challenges, with 57% living in extreme poverty and 52% being illiterate. These factors hinder their economic advancement, perpetuating a cycle of poverty that also affects their families and communities, particularly as male children often enter the fishing profession early, exacerbating intergenerational poverty. Despite some support from governmental and non-governmental organizations, fisherwomen continue to struggle with high-interest loans and a lack of technical knowledge. To empower these women and improve their socioeconomic status, the study recommends several key actions: providing alternative income sources during fishing bans, facilitating access to microfinance, offering tailored technical training and ongoing support, improving access to education, enhancing interagency collaboration, and conducting further research to address specific gaps and challenges. These measures aim to integrate fisherwomen into relevant policy frameworks and ensure their long-term empowerment and well-being.

Ethical approval

The author declares that this study complies with research and publication ethics.

Informed consent

Not available.

Conflicts of interest

There is no conflict of interests for publishing of this study.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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RESEARCH PAPER

Finfish harvest trends in the Chalakudy River within the Western Ghats biodiversity hotspot in the Southwest of India

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Abstract

Accurate quantification of fish harvest is a crucial prerequisite for effective fisheries management. This study aimed to estimate the finfish harvest in the Chalakudy River, a vital riverine aquatic ecosystem located in the Western Ghat biodiversity hotspot on Southwest coast of India. The research was conducted from June 2019 to May 2020, covering major fish landing centres, to provide essential data for sustainable fisheries management and conservation of this critical ecosystem. The total fishery yield from the Chalakudy River was estimated at 68.53 tonnes, comprising 68 finfish species across 37 families. Seasonal variations in fish landings were observed, with the post-monsoon season accounting for the highest yield (38.34%) and the pre-monsoon season the lowest (28.87%). The family Cyprinidae dominated the catch, with 19 species, followed by Cichlidae (5 species), Channidae, and Bagridae (three species each). Cyprinids (48.42%), cichlids (14.56%), catfishes (12.66%), and murrels (8.79%) constituted the major fish groups that contributed to the fishery. The landings were represented by one critically endangered (CR) (*Hypselobarbus thomassi*), two endangered (EN) (*Osteochilichthys longidorsalis,* and *Tor malabaricus*) and five vulnerable (VU) (*Hypselobarbuas kolus, Hyporhamphus xanthopterus, Wallago attu, Channa diplogramma* and *Horabagrus brachysoma*) fish species. The dominant fish species in the fishery were *Cyprinus carpio* (6.36 t), *H. kolus* (5.23 t), *Barbodes carnaticus* (4.85 t), *Etroplus suratensis* (4.07 t), and *T. khudree* (3.46 t). Notably, the fishery included 15 non-native species, comprising 12 exotic species introduced from outside India and three species transplanted from Northeast India. Gill nets (91.77%) was the dominant gear used in the riverine fishery followed by seine nets (4.99%), hooks and lines (2.02%), cast nets (0.98%) and fish traps (0.23%). Our research findings indicates that the fish population in the river is under severe pressure with significant catches of non-native fish species posing challenges to the survival of indigenous fish species.

Introduction

Inland capture fisheries exploit wide variety of fishery resources in various inland water ecosystems including rivers, reservoirs, flood plains, wetlands, lakes, canals, and even rice fields (Funge-Smith and Bennett, 2019). They are diverse, use multiple species, are often geographically dispersed, and involve commercial, subsistence, small-scale, and aquaculture components (Cooke et al., 2016). These fisheries play a vital role in global food production, contributing 11.5 million tonnes in 2020, which represents 12% of the total global fish catch (FAO, 2022). The majority of inland fishers operate in the small-scale sector, ranging from family-based artisanal units in small lakes or larger river channels to commercial enterprises with motorized boats (Welcomme et al., 2010). These fishes are traded in the local fish market and a substantial part of the fishery may be consumed by inland urban dwellers (Welcomme et al., 2010). Small-scale inland fisheries not only contribute to nutrition, food security, and the national economy but also the livelihoods of up to 820 million fishers and fish workers across the world (Kanthiah, 2010; Silvano and Kurien, 2023). Globally, small-scale fisheries account for over half of the world's total fish catch, with a significant 90-95% of their catch being consumed locally (FAO, 2022). In various regions of Africa and Asia, small-scale fisheries play a vital role in harvesting large-sized freshwater species, which are highly valued for both food security and medicinal purposes (Belton and Thilsted, 2014). Despite the important contributions, inland fish and fisheries generally remain economically and socially undervalued and biologically underappreciated because accurate information about this small-scale highly dispersed sector is inherently difficult to acquire (Youn et al., 2014; Allan et al., 2005). However, inland fisheries face myriad threats such as overfishing, destruction of fish habitats, flooding events, water pollution, increasing human population, and demand for land in coastal areas (Barange et al., 2018). Though having immense importance, global studies regarding small-scale inland fisheries like fishing gear, seasonality, catch composition, and catch per unit effort (CPUE) are limited.

The global inland fisheries catch is predominantly concentrated in tropical and subtropical regions, with India emerging as the leading producer in 2020, accounting for an impressive 1.8 million tonnes of capture production (FAO, 2022). The inland fisheries sector makes a notable contribution to India's economy, accounting for approximately 1% to the National Gross Value Added (GVA) and 5.43% to Agricultural GVA. Moreover, this sector supports the livelihoods of over 14.5 million people directly and almost twice the number along the value chain (NIFAP, 2019). India's inland water bodies, comprising rivers, estuaries, reservoirs, freshwater lakes, and streams, play a vital role in the country's fish production, supporting a diverse array of fish species. The riverine resources of India have been approximately 3.12 million km^2 and the fish productivity from these rivers varies from 0.64 to 1.64 tonnes per km (CEBPOL, NBA, 2018). The majority of these river-caught fishes were consumed locally, contributing to the food security of millions of people directly and indirectly dependent on fishing and related activities (Montaña et al., 2011; Raghavan et al., 2011). The fishery resources in many Indian riverine waters are still harvested using traditional fishing methods and gear. The choice of fishing gear in these riverine habitats is often dictated by the target species, fishing location, season, and fish abundance, resulting in a diverse range of fishing gear being employed, including gill nets, cast nets, seine nets, drag nets, and hook and lines. Due to the absence of consistent and accurate data on riverine fisheries, it becomes challenging to pinpoint trends in fisheries production within these river systems. The reasons for poor data related to riverine fisheries are due to the widely dispersed fish landing centres, high seasonal nature of catch, low economic value, extended livelihood activities of fishers, and local and domestic trade of catch (Bartley et al., 2015).

The Western Ghats a discrete biogeographical region along the west coast of peninsular India has been designated a global biodiversity hotspot because of its remarkable diversity and high level of endemic species (Myers et al., 2000). 320 species of freshwater fishes including 212 endemic fishes and one-third threatened fishes reported from the streams and rivers originating from the Western Ghats ecoregion (Dahanukar and Raghavan, 2013). A total of 54 finfish species are being exploited in the major rivers of Kerala, which originate from the Western Ghats (Renjithkumar, 2015). The total annual catch from these rivers is estimated at 854.75 tons. The fishing gear used in these rivers includes gill nets, cast nets, seine nets, drag nets, and hook and line, highlighting the diverse and extensive fishing practices in the region (Renjithkumar, 2015). Chalakudy River, originating from the Anamalai hills of the Western Ghats, is the fifth-longest among Kerala's 44 perennial rivers (Ajithkumar et al., 1999). The river harbours a rich and diverse fish fauna of 98 species, and many of them are endemic (36%) and threatened (33%) (Ajithkumar et al., 1999; Raghavan et al., 2008a). The indigenous ornamental fish resources of Chalakudy River are considered to be in high demand in the international aquarium fish markets and the river has currently become a hotspot for their indiscriminate collection of ornamental fishes (Sekharan et al., 2002; Raghavan et al., 2008a). Habitat destruction, overexploitation of fish for food and ornamental purposes, pollution, and introduction of exotic fish species due to extreme climate events and illegal and unmanaged aquaculture menacing the fish fauna in the river (Raghavan et al., 2008b; Raj et al., 2021). Despite the importance of fisheries conservation, research on the quantification of exploited fisheries in Kerala's rivers is scarce, with only a few notable exceptions in the Pampa, Kallada, Bharathapuzha, and Muvattupuzha Rivers (Renjithkumar et al., 2011, 2016, 2020, 2021). Despite earlier research on the fish fauna diversity in Chalakudy River (Ajithkumar et al., 1999; Raghavan et al., 2008a), there is a significant knowledge gap regarding the exploited fishery in this river. To address this, the present study aimed to: (1) determine the species-wise harvest (2) assess the landing centre-wise harvest (3) evaluate fishing gear-wise harvest. The findings of this study will inform the development of targeted conservation measures, ensuring the sustainable harvest and conservation of native fish fauna in the Chalakudy River.

Materials and methods

Study area

Chalakudy River (10°10’0” to 10°33’30” N; 76°17’0” to 77°4’0” E) is 145 km long and is one of the major river systems in Kerala state originates from the Anaimalai and Nelliampathy Hills of Southern Western Ghats and flows through three districts namely Palakkad, Thrissur, and Ernakulam before emptying into the Arabian Sea (Fig 1). The drainage area of the Chalakudy River basin is around 1704 km^2, 1404 km^2 lies in Kerala, and the rest of the 300 km^2 flows through Tamil Nadu state (Nameer and Raghavan, 2019). The river receives an average annual rainfall of 3600 mm and an annual stream flow of 169.3 mm^3 (Parvathy and Thomas, 2021). Out of the total area of the river basin, 54% is occupied by dense forest, 12% by plantation crops, 14% by agricultural plantations, and 16% comes under homesteads with crops in Kerala and Tamil Nadu state (Chattopadhyay and Rani, 2005).

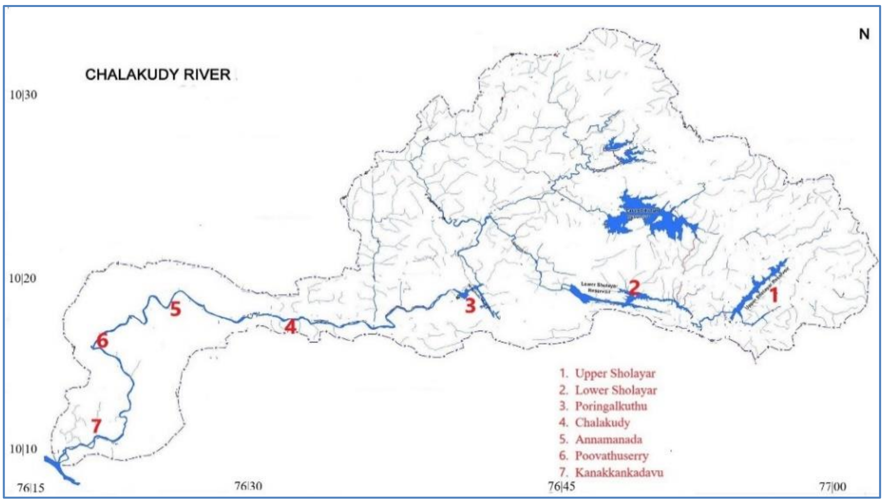

Figure 1. Map showing the stretch of Chalakudy River, Western Ghats, India along with study locations.

Methodology

The selection of sampling stations was based on a preliminary survey conducted in a month, covering the full gradient of the river. The locations were identified following interviews conducted with local fishermen and residents living in the river's vicinity. It was determined that there are seven primary fish landing centres: Upper Sholayar (10°18'22.84"N, 76°53'14.43"E), Lower Sholayar (10°19'02.24"N,76°44.06"57E), Poringalkuthu (10°18'47.55"N,76°38'06.75"E), Chalakudy (10°17'40.08"N,76°20'14.70"E), Annamanada (10°14'29.00"N,76°19'49.23"E), Poovathuserry (10°12'16.15"N, 76°19'22.93"E) and Kanakkankadavu (10°10'27.54"N,76°16'24.36"E) (Fig.1). These seven landing sites are the main locations where commercial fishermen bring their catches for sale. The exploited fishery was estimated from June 2019 to May 2020 based on regular systematic surveys and stratified random sampling method was carried out on major landing sites of the river on a monthly basis. The fishing activity of the study locations was monitored in the early morning (6-8 am) and information on catches was collected from more than 30% of total gears operated, giving importance to the species-wise total weight, type of gear, and mesh size, fishing hours and manpower involved (Kurup et al., 1993). Fish specimens collected were preserved in 8% formalin and identified using standard keys (Talwar and Jhingaran, 1991; Jayaram, 2009). Based on interviews, the number of fishermen on a given day at a given landing site varied from 4–12 individuals. The number of fishermen in a day may be influenced by fluctuations in fish availability and season. The catch from every fisherman who arrived at a given landing site on a given morning was examined. The landing data were pooled into three seasons, monsoon (June- September), post-monsoon (October-January), and pre-monsoon (February-May).The daily species-wise landings from each type of gear were computed following Kurup et al. (1993), using the formula: w= (W/n) x N, where, w= total weight of species; W= total weight of species from gear sampled; n = number of gears sampled; and N = total number of similar gears operated. The monthly production was estimated by multiplying daily landings with the total number of fishing days in a month. The annual exploited quantity was calculated by adding the landings of all the seasons. The gear-wise CPUE (catch per unit effort) for fish caught per unit hour of operation was calculated by dividing the total sampling gear catch in biomass (TSGCB) which is the observed value of fish caught by a particular gear, by total sampling effort hours (TSEH) (Ghosh and Biswas, 2017; Renjithkumar et al., 2011) TSEH is calculated as the product of average sampling effort hour of operation of a particular gear per day and total numbers of such gear used, i.e. sampling gear density.

CPUE (g/h) = TSGCB ÷ TSEH

Results

Species composition in the catch

Exploited fish diversity of Chalakudy River comprised 68 species belonging to 51 genera and 37 families (Table 1). Family Cyprinidae was the most diverse family representing 19 species followed by Cichlidae (5 species), Channidae, and Bagridae (3 species each). Based on IUCN criteria, the landings were represented by one critically endangered (EN) (*Hypselobarbus thomassi*), 2 endangered (EN) (*Osteochilichthys longidorsalis* and *Tor malabaricus*), and 5 vulnerable (VU) (*H. kolus*, *Hyporhamphus xanthopterus*, *Wallago attu*, *Channa diplogramma*, and *Horabagrus brachysoma*) fish species (Fig 2). 15 alien fish species were recorded in the fishery of which 12 (*Atractosteus spatula, Ctenopharyngodon idella*, *Cyprinus carpio, Hypophthalmichthys molitrix*, *Oreochromis niloticus*, *O. mossambicus*, *Mayaheros urophthalmus*, *Osphronemus goramy*, *Clarias gariepinus*, *Pangasianodon hypophthalmus*, *Pterygoplichthys multiradiatus* and *Piaractus brachypomus*) are exotic to the country; while rest were the Indian major carps (*Labeo rohita, L. catla*, and *Cirrhinus mrigala*) transplanted from Gangetic plains of Northern India.

Table 1. Species composition and landing in the exploited fishery of Chalakudy River, India

SL no	Order	Family	Species	Landing (t)	IUCN
1	Elopiformes	Elopidae	*Elops machnata*	0.07	LC
2		Megalopidae	*Megalops cyprinoides*	1.01	LC
3	Anguilliformes	Anguillidae	*Anguilla bengalensis*	0.29	NT
4	Clupeiformes	Clupeidae	*Dayella malabarica*	0.08	LC
5		Engraulidae	*Thryssa dussumieri*	0.05	LC
6	Gonorhynchiformes	Chanidae	*Chanos chanos*	0.11	LC
7	Cypriniformes	Cyprinidae	*Amblypharyngodon microlepis*	0.23	LC
8			*Barbodes carnaticus*	4.85	LC
9			*Cirrhinus mrigala*	1.69	LC
10			*Ctenopharyngodon idella*	0.50	EX
11			*Cyprinus carpio*	6.36	EX
12			*Dawkinsia filamentosa*	1.87	LC
13			*Labeo catla*	0.56	LC
14			*Hypselobarbus kolus*	5.23	VU
15			*Hypselobarbus kurali*	0.61	LC
16			*Hypselobarbus thomassi*	0.15	CR
17			*Hypophthalmichthys molitrix*	0.31	EX
18			*Labeo dussumieri*	1.49	LC
19			*Labeo rohita*	2.19	LC
20			*Osteobrama bakeri*	0.19	LC
21			*Osteochilichthys longidorsalis*	0.32	EN
22			*Puntius mahecola*	0.92	DD
23			*Systomus subnasutus*	1.16	LC
24			*Tor khudree*	3.46	LC
25			*Tor malabaricus*	1.08	EN
26	Siluriformes	Bagridae	*Horabagrus brachysoma*	2.01	VU
27			*Mystus gulio*	0.39	LC
28			*Mystus oculatus*	0.02	LC
29		Siluridae	*Ompok malabaricus*	0.90	LC
30			*Wallago attu*	0.83	VU
31		Pangasiidae	*Pangasianodon hypophthalmus*	1.39	EX
32		Clariidae	*Clarias dussumieri*	0.04	NT
33			*Clarias gariepinus*	0.15	EX
34		Heteropneustidae	*Heteropneustes fossilis*	2.68	LC
35		Ariidae	*Arius maculatus*	0.12	NE
36		Loricariidae	*Pterygoplichthys sp*	0.14	EX
37	Beloniformes	Belonidae	*Xenentodon cancila*	0.17	LC
38		Hemiramphidae	*Hyporhamphus xanthopterus*	0.26	VU
39	Synbranchiformes	Mastacembelidae	*Macrognathus aral*	0.16	LC
40			*Mastacembelus armatus*	0.11	LC
41	Perciformes	Ambassidae	*Parambassis dayi*	1.24	LC
42			*Parambassis thomassi*	0.74	LC
43		Latidae	*Lates calcarifer*	0.10	LC
44		Serranidae	*Epinephelus malabaricus*	0.17	LC
45		Sillaginidae	*Sillago sihama*	0.16	LC
46		Carangidae	*Caranx ignobilis*	0.21	LC

47		Leiognathidae	*Leiognathus equula*	0.09	LC
48		Lutjanidae	*Lutjanus argentimaculatus*	0.15	LC
49			*Lutjanus malabaricus*	0.22	LC
50		Gerreidae	*Gerres filamentosus*	0.07	LC
51		Nandidae	*Nandus nandus*	0.57	LC
52		Pristolepididae	*Pristolepis rubripinnis*	0.05	NE
53		Mugilidae	*Mugil cephalus*	0.10	LC
54		Cichlidae	*Etroplus suratensis*	4.07	LC
55			*Oreochromis mossambicus*	2.94	EX
56			*Oreochromis niloticus*	2.47	EX
57			*Pseudetroplus maculatus*	0.45	LC
58			*Mayaheros urophthalmus*	0.05	EX
59		Gobiidae	*Glossogobius giuris*	0.50	LC
60		Scatophagidae	*Scatophagus argus*	0.31	LC
61		Anabantidae	*Anabas testudineus*	0.84	DD
62		Osphronemidae	*Osphronemus goramy*	0.55	EX
63		Channidae	*Channa diplogramma*	0.29	VU
64			*Channa pseudomarulius*	2.48	LC
65			*Channa striata*	3.26	LC
66	Pleuronectiformes	Soleidae	*Brachirus orientalis*	0.11	LC
67	Lepisosteiformes	Lepisosteidae	*Atractosteus spatula*	0.10	EX
68	Characiformes	Serrasalmidae	*Piaractus brachypomus*	2.06	EX
		Total		68.53	

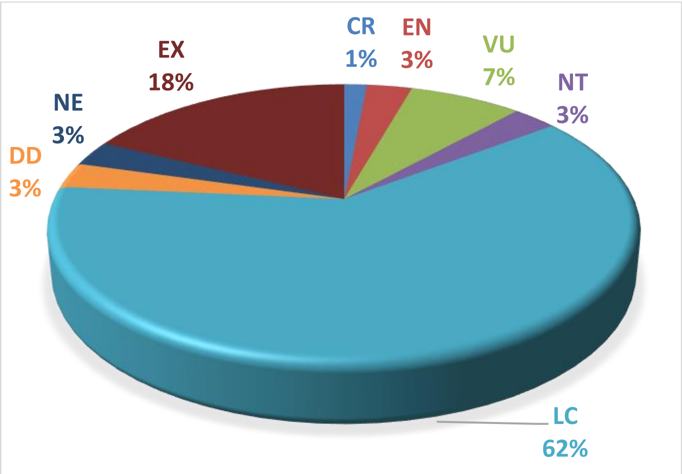

Figure 2. Biodiversity assessment of fish species in the exploited fishery of River Chalakudy, India.

Estimates of fish production

The annual exploited fishery of the river for a period of one year (2019-2020) was estimated to be 68.53 t. The highest landings were reported in the post-monsoon season (38.34%) and the lowest during the pre-monsoon season (28.87%). Cyprinids (48.42%), cichlids (14.56%), catfishes (12.66%), and murrels (8.79%) constituted the major fish groups that contributed to the fishery. *C. carpio* contributed the highest in the catch (9.28%) followed by *H. kolus* (7.64%), *Barbodes carnaticus* (7.08%), *Etroplus suratensis* (5.94%), and *Tor khudree* (5.05%). Cyprinids represented 19 species and contributed 48.43% to the annual fish landing. The main cyprinids are *C. carpio*

(6.36 t), *H. kolus* (5.23 t), *B. carnaticus* (4.85 t) and *T. khudree* (3.45 t). Cichlids contributed 14.57 % of the total landing comprised of five species viz., *E. suratensis* (4.07 t), *O. mossambicus* (2.94 t), *O. niloticus* (2.47 t), *Pseudetroplus maculatus* (0.45 t) and *Mayaheros urophthalmus* (0.05 t). Catfishes mainly *Heteropneustes fossilis* and *Horabagrus brachysoma* contributed 2.68 t and 2.01 t respectively in the fish landing. Murrels were represented by *Channa pseudomarulius*, *C. striata* and *C. diplogramma*, contributed 2.47 t, 3.26 t, and 0.29 t, respectively in the catch. Monthly fluctuations of the fishery resources in the river indicated the highest quantity in August (7.35 t) and lowest in May (3.41 t).

Exotic and transplanted species contributed 24.84% and 6.48% respectively in the exploited fishery. The important exotic species are *C. carpio* (6.36 t) followed by *O. mossambicus* (2.94 t), *O. niloticus* (2.47 t) and *P. brachypomus* (2.06 t). 17 secondary freshwater fish species including *Megalops cyprinoides* (1.01 t), *Scatophagus argus* (0.31 t), and *Hyporhamphus xanthopterus* (0.26 t) contributed 4.83% in the fishery. The period between May to July showed a lower fishing activity even though an increasing trend was noticed from August to January. The landing centre-wise fishery showed that the highest landing was reported in Kanakkankadavu (16.18 t) followed by Annamanada (11.11 t) and Upper Sholayar (10.49 t). Among the threatened fish groups, critically endangered (EN) *H. thomassi* contributed 0.15 t whereas endangered (EN) (*O. longidorsalis* and *T. malabaricus*) contribute 0.32 t and 1.08 t respectively to the annual fish landing.

Gear-wise fish landing

Gill nets formed the most dominant fishing gear operated in the river contributing 91.77% to the fish landing followed by seines (4.99%), hooks and lines (2.02%), cast nets (0.98%) and traps (0.23%) (Fig. 3). Gill nets operated varied from 75-150 cm in length with a mesh size range of 20-80 mm. The main fish species caught in gill nets were *C. carpio, B. carnaticus, E. suratensis, H. kolus, T. khudree,* and *O. mossambicus.* These nets are of different names locally *Odakkuvala* and *Neettuvala* which differ from each other in the mode of fabrication, length, and mesh sizes. For gillnets, the highest catch per unit effort (CPUE) was recorded for *C. carpio* (2.09 kg h^{-1}) followed by *H. kolus* (2.01 kg h^{-1}), *B. carnaticus* (1.80 kg h^{-1}), *E. suratensis* (1.3 kg h^{-1}) and *T. khudree* (1.26 kg h^{-1}) (Fig. 4). Gill nets are operated throughout the length of the river, unlike other gears, widely used in upper reaches of the river especially in reservoirs. Gill net is usually operated as drift or set in the water column by one or two fishermen from a canoe mainly made up of wood.

Seine nets are locally known as *koruvala* and it is mainly used for the exploitation of small-sized fishes. The net is rectangular made of nylon (PA) multifilament having a 6-18 mm mesh size. One end of the net is handed over to the fisherman standing in the water and the other fisherman releases the net from the canoe in a circular fashion along the direction of water flow to spread the net properly. Simultaneously the other end of the net is taken inside the circle by the second fisher and he moves circularly to collect fish into the pocket on the same side of the net. Depending on the water depth and conditions 6-10 hauls/ day/net could be made. The main fish species caught in seine nets were *Dawkinsia filamentosa*, *Parambassis dayi*, *Puntius mahecola*, *Anabas testudineus,* and *Heteropneustes fossilis*. The net is operated mainly during the pre-monsoon season with low water levels in the river preferably during day and night. In seines, the highest catch per unit effort was recorded for *D. filamentosa* (0.38 kg h^{-1}) followed by *P. dayi* (0.33 kg h^{-1}), *P. mahecola* (0.31 kg h^{-1}), *H. fossilis* (0.25 kg h^{-1}) and *A. testudineus* (0.24 kg h^{-1}) (Fig. 5).

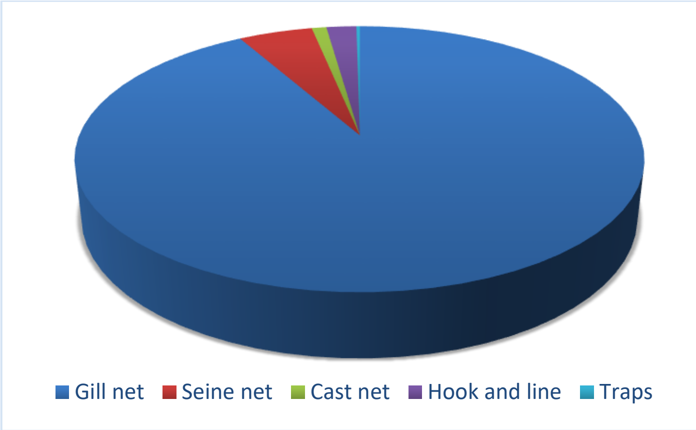

Figure 3. Percentage contribution of various gears in the exploited fishery from the River Chalakudy, India.

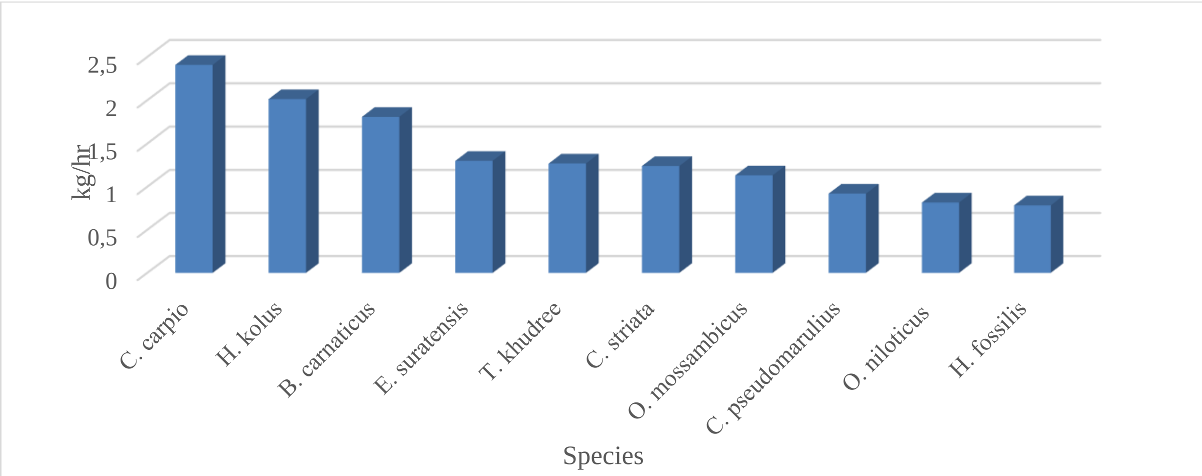

Figure 4. Catch per unit hour of major fish species exploited by gillnets in the River Chalakudy, India.

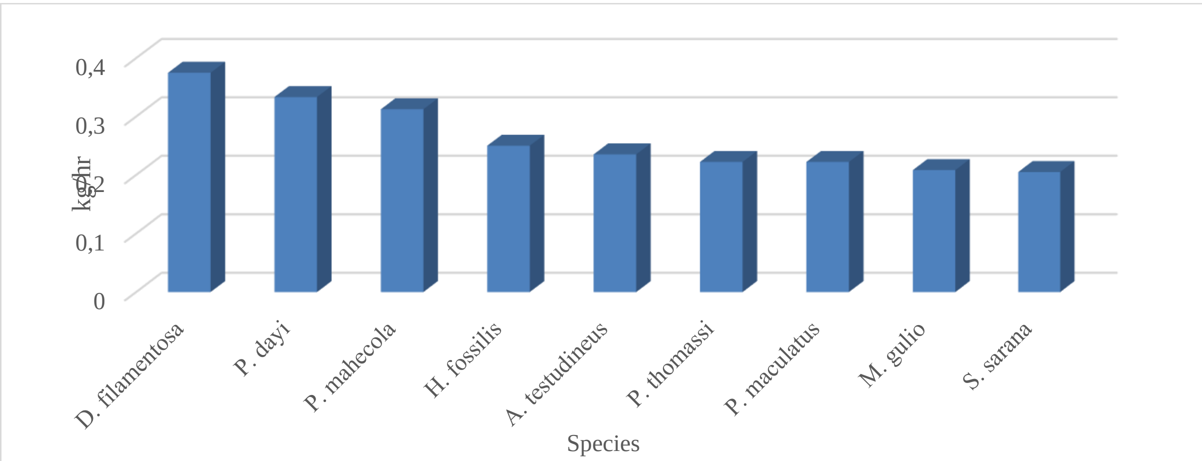

Figure 5. Catch per unit hour of major fish species exploited by seine nets in the River Chalakudy, India.

Hook and lines were used to catch *Anguilla bengalensis, T. khudree, B. carnaticus, Wallago attu*, and *C. carpio. A. bengalensis* (0.4 kg h^{-1}) recorded the highest CPUE for *A. bengalensis* (0.4 kg h^{-1}) in hook and lines followed by *T. khudree* (0.33 kg h^{-1}), *B. carnaticus* (0.30 kg h^{-1}) and *W. attu* (0.26 kg h^{-1}). (Fig. 6). The length of the line varied from 3 to 40 m in length according to the depth and flow of the water area where the gear is operated. The commonly used baits were live or dead prawns and small fishes and a small thermocole or cork or sponge float is used in calm waters. Cast nets are mainly used for the capture of small shoaling fishes such as *D. filamentosa*, *P. dayi*, *Mystus gulio*, *A. microlepis*, and *P. maculatus*. Highest catch per unit effort for *D. filamentosa* (0.71 kg h^{-1}) followed by *P. dayi* (0.58 kg h^{-1}), and *M. gulio* (0.39 kg h^{-1}) (Fig 7) in cast nets.

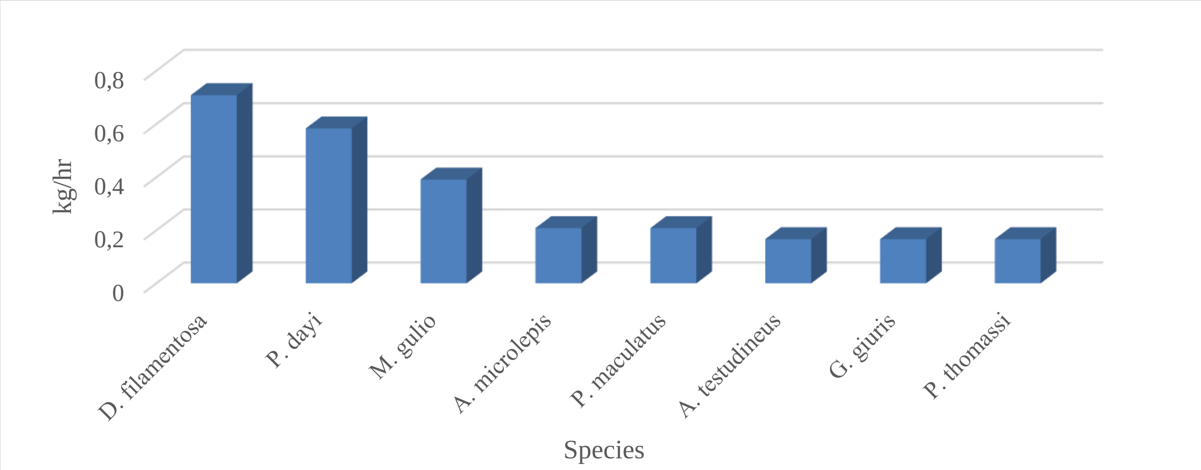

Figure 6. Catch per unit hour of major fish species exploited by hook and lines in the River Chalakudy, India

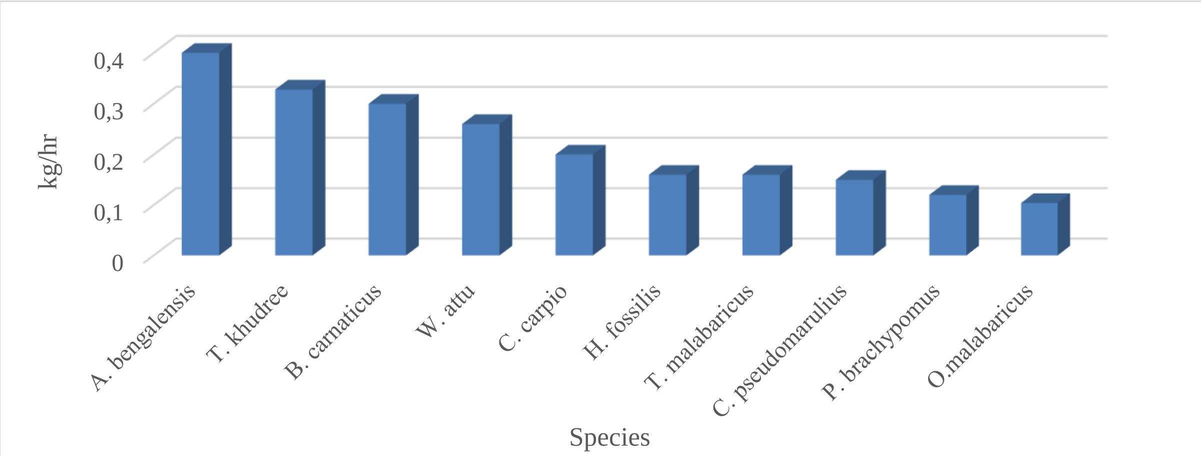

Figure 7. Catch per unit hour of major fish species exploited by cast nets in the River Chalakudy, India.

Discussion

The Chalakudy River's exploited fishery stands out for its remarkable diversity, supporting a total of 68 fish species. This is significantly higher than the number of species found in other rivers of the Western Ghats region, including Bharathapuzha (31 species), Pampa (26 species), Muvattupuzha (23 species), and Kallada (21 species) (Renjithkumar et al., 2011, 2016, 2020, 2021). Raghavan et al. (2008a) reported 71 fish species, including five exotic species, while Ajithkumar et al. (1999) documented a higher total of 98 species, including 12 secondary freshwater and migratory fishes in the Chalakudy river system. The family Cyprinidae which include carps, barbs, and minnows held dominance among various fish groups, with a numerical strength of 19 species accounting for 25% of the total fish species. Raghavan et al. (2008a) also observed the prominence of the Cyprinidae family, documenting 24 species belonging to this family in the Chalakudy River. The present study revealed that the annual exploited fish landing in the Chalakudy River was 68.53 tonnes, which is relatively lower compared to the total landings in the Pampa (394.22 t) and Bharathapuzha Rivers

(112.56 t) (Renjithkumar et al., 2011, 2020). However, the fishery of the Muvattupuzha River (45.01 t) and Kallada River (16.58 t) recorded even lesser annual fish landings when compared to the present study (Renjithkumar et al., 2016, 2021). The threat status of fishes in river represented one critically endangered (CR), two endangered (EN), and five vulnerable (VU) fish species contributed respectively 0.22 %, 2.04%, and 12.59% to the annual fishery. Rajeev et al. (2008a) reported 4 'critically endangered' (CR), 16 'endangered' (EN), and 11 'vulnerable (VU) from this river system. Migratory and secondary freshwater fishes like *Megalops cyprinoides*, *Scatophagus argus*, *Hyporhamphus xanthopterus*, *Epinephelus malabaricus*, *Lutjanus malabaricus* and *L. argentimaculatus* have been observed in the midstream regions of the river, extending their habitat up to approximately 60 km. The increased salinity gradient, suitable breeding habitat, availability of food niches, and food abundance in the riverine area, and climate change in the ocean are the major factors responsible for the migration (Brönmark et al., 2014). Migratory fishes contributed to 3.56% of the fishery in the Bharathapuzha River (Renjithkumar et al., 2020).

Tribal people and forest-dwelling communities residing in the upper reaches of the Chalakudy River basin are highly dependent on the native fish species for their sustenance and livelihoods (Raghavan et al., 2008a). These communities have traditionally depended on the river's fish resources, which are an integral part of their food security, cultural practices, and economic well-being. The forest-dwelling communities in the Chalakudy River basin primarily exploit a range of native cyprinid species, including *T. khudree*, *H. kolus*, *B. carnaticus*, and *O. longidorsalis*, and introduced species like the *C. carpio* and *Oreochromis mossambicus*. *T. khudree* (Deccan mahseer) and *T. malabaricus* (Malabar mahseer) are highly valued food and game fish species in India, inhabiting the fast-flowing streams and rivers of the country's hilly regions. In the Chalakudy River fishery, these species are prized catches, with a total landing of 4.54 t. In the Pampa River, *T. khudree* contributed an annual landing of 0.65 t, while in the Kallada River, it accounted for 0.36 t of the annual landing (Renjithkumar et al., 2011, 2021). Cast nets and gill nets were the primary fishing gears utilized for the exploitation of mahseer in the Periyar and Chalakudy Rivers within the Western Ghats. Unfortunately, in some areas, there were reports of indiscriminate fishing practices involving dynamite and poison, posing a threat to the fish populations and the overall river ecosystem (Raghavan et al., 2011). The mahseer species catches in Periyar Lake and Chalakudy River have experienced a drastic decline over the recent years (Minimol, 2000; Raghavan et al., 2011). The introduced species *C. carpio* and *O. mossambicus* pose a significant threat to the native *T. khudree* population in Periyar Lake (Kurup et al., 2006). The fishing mortality rate of *T. khudree* in Poringalkuthu Reservoir in Western Ghats was one of the highest of any other species of mahseer in India and this is due to the indiscriminate exploitation of the species (Raghavan et al., 2011) highlighting the need for urgent conservation measures to regulate fishing practices and protect this valuable species from overfishing. The decline in the fishery of mahseer due to indiscriminate fishing of brood and juvenile fish and adverse effects of dams (Bhatt et al., 2000, 2004; Nautiyal et al., 2008). The introduction of *O. mossambicus* to Periyar Lake, Kerala, has posed a significant threat to the survival of *T. khudree*. A remarkable 78% overlap in their dietary preferences has been observed, indicating intense competition for limited resources. Furthermore, *C. carpio* has been found to exhibit a significant 57% overlap in its dietary preferences with those of *T. khudree*, indicating another potential source of competition for resources in the ecosystem (Kurup et al., 2006). Two crucial management strategies have been identified for the conservation of *T. khudree*: firstly, regulating fishing efforts to prevent overfishing and reduce pressure on the species, and secondly, implementing a breeding season ban on fishing (October to December) to protect the species during its most vulnerable life stage (Arun et al., 2001; Raghavan et al., 2011).

H. brachysoma commonly known as Asian Sunfish formed the mainstay in the exploited fisheries of the rivers of Kerala (Sunil et al., 1999) and contributed 17.11 t and 3.67 t in Pampa and Muvattupuzha Rivers respectively (Renjithkumar et al., 2011, 2016). The landing of *H. brachysoma* in the Chalakudy Rivers was low (2 t) when compared to these rivers. It is one of the important food fish species that is exploited frequently by artisanal fishermen using gill nets, hook and lines, and drag nets (Sreeraj et al., 2007; Prasad et al., 2012). The populations of golden catfish have declined drastically and the fish are restricted to tributaries of Chalakudy, Meenachil, Manimala, and Pamba Rivers (Padmakumar et al., 2011). *H. brachysoma* is an important catfish species that is largely exploited during their breeding migration in rivers during monsoon floodplain fishery (Shaji and Laladhas, 2013) and more than 100 kg of mature *H. brachysoma* are caught in a week-long monsoon floodplain fishery (Shaji and Laladhas, 2013). Overexploitation, habitat destruction, invasion of exotics, and pollution have resulted in the population decline of the species (Raghavan et al., 2016). Various management strategies including restrictions on fishing gear, enforcement of minimum size limits, implementation of closed fishing seasons, and fish sanctuaries should be adopted for the conservation of this catfish species (Raghavan et al., 2016).

Murrels, also known as snakeheads, are highly prized food fish in tropical Asia, renowned for their unique flavour and nutritional value (Wee, 1982), and the third most important group of freshwater fishes in India after carps and catfishes (Laxmappa, 2017). Snakeheads play a vital role in small-scale fisheries in India, making a significant contribution to the catch in rivers and reservoirs across the country's and are also popular for pond and cage aquaculture (Adamson, 2010; Poulsen et al., 2008; Ali et al., 2013). The three snakeheads (*Channa striatus, C. pseudomarulius,* and *C. diplogramma*) contributed to a significant fishery (6.02 t) in the Chalakudy River. *C. pseudomarulius* (great snakehead) is considered an important food fish in India showed a high landing in Pampa River (30.36 t) when compared to Chalakudy River (2.47 t) and a low landing in Muvattupuzha (2.24 t) and Bharathapuzha Rivers (0.34 t). *C. striatus* commonly known as 'Cherumeen' in vernacular contributed an annual landing of 3.26 t in the river. The landing of the species was highest in the Pampa (36.34 t) and Muvattupuzha (4.60 t) Rivers compared to Chalakudy River. *C. diplogramma* commonly known as Malabar snakehead (*Puli vaka* in vernacular) contributed a low landing (0.29 t) in Chalakudy River. In Pampa River, this species also showed a reduced landing (0.79 t) (Renjithkumar et al., 2011). This species showed an alarming decline in its population due to destructive type fishing activities including dynamiting and poisoning, overexploitation for food and international aquarium trade, Epizootic Ulcerative Syndrome (EUS), habitat alteration, and pollution, and local fishers operating in the rivers have confirmed that populations have declined considerably (> 90%) over the last two decades (Benziger et al., 2011; Sajeeven et al., 2014; Kurup, 2000).

Data on the exploited fishery of Chalakudy River indicate that pearl spot, *E. suratensis* (4.07 t) is one of the dominant fish species that appeared in the landing. This species is economically important both as food fish and aquaculture candidates in its home range and contributes significantly to the inland fishery of Kerala (Roshni et al., 2017). This species contributes a high landing in Pampa (31.88 t) and Bharathapuzha (4.23 t) Rivers (Renjithkumar et al., 2011; 2020). A decline in the landings of *E. suratensis* from 1252 t (1969), 458 t (1989), and 200 t (2002) to 135.28 t (2012-13) indicate a high reduction in the stock of the species in the Vembanad Lake of central Kerala (Samuel, 1969; Kurup et al., 1995; Padmakumar et al., 2002; Roshni et al., 2017). The major threats to the reduction of the species in their native habitats are to degradation of their breeding grounds habitats and the indiscriminate collection of mature fishes owing to their immense market value may gradually lead the fish to a death hole (Roshni et al., 2017). The government of Kerala state declared *E. suratensis* as a "State fish" due to very little attention that has been received towards the protection of the species (Padmakumar et al., 2012).

Gillnets are simple, selective, and inexpensive fishing gear, which, therefore, is one of the most widely used gears by small-scale fishermen in the inland waters of India (Remesan and Ramachandran, 2005). The gillnet was the primary fishing gear employed in the Chalakudy River, accounting for a staggering 91.77% of the total annual fish catch. The gillnet catches in the Chalakudy River are dominated by four key species: *C. carpio*, *B. carnaticus*, *E. suratensis*, and *H. kolus*. According to research conducted by Renjithkumar et al. (2011, 2016, 2020, 2021), gillnets are the predominant fishing gear in several rivers in the region, including Pampa (77%), Muvattupuzha (88%), Bharathapuzha (87%), and Kallada (99%). Gill nets are easy to use, even in difficult environmental conditions, and were used for fishery exploitation in riverine waters in Kerala state (Baiju and Hridayananthan, 2003). Gill net is the only gear in which the 'mesh' of the gear itself aids in obtaining the maximum yield, protecting small fishes, and minimizing escapement of injured or dying fishes (Ishida,1961; Ueno et al., 1965; Thomson et al., 1971).

Seine net is a fine-meshed net operated in the lower stretches of the Chalakudy River and the main species caught in the nets are *D. filamentosa*, *P. dayi*, and *P. mahecola*. Indiscriminate collection of these small-sized ornamental species for the aquarium trade is considered to be one of the major threats to the fish fauna of Chalakudy River (Raghavan et al., 2008a). Hook and lines have three types of categories viz., (i) hand lines (ii) rod & lines, and (iii) long lines. Hand lines is the simplest form made of polyamide monofilament lines with single hooks were prevalent in the river. In Pampa River, hooks and lines are commonly used during post-monsoon season for catching mainly *W. attu* (Renjithkumar et al., 2011). Hook & lines accounted for only 1% of the total fish landing in Bharathapuzha River and the major species consisted of *C. striata*, *C. marulius*, and *Mastacembelus armatus*. The cast nets are generally made of PA multifilament and the length and mesh size of the gear varies from 2 to 4.5 m length and 6-20 mm respectively. They are generally operated throughout the year in the Pampa River, including during June - August when the river gets flooded with monsoon runoff (Renjithkumar et al., 2011). Stringed and stringless cast nets were common in the downstream areas of Chalakudy River, and in upstream areas, mainly stringless cast nets were used.

The introduction of alien or non-native fish species for aquaculture and ornamental purposes poses a significant threat to freshwater ecosystems globally (Ehrenfeld, 2010). This study reveals a concerning trend, with alien species accounting for 31.32% of the total fish catch in the river. Notably, 12 of these species are non-native to the country, while the remaining three are Indian major carps (IMCs) that were introduced from the Gangetic plains for aquaculture purposes. The threats posed by these invasive species involve the decline of native biodiversity, extinction of endemic and threatened species, habitat alterations, introduction of new parasites or diseases, and production of hybrid fishes (Singh and Lakra, 2011). The introduction of Indian Major Carps (IMCs) into Kerala's riverine ecosystems was intended to enhance capture fisheries (Sugunan, 2000). However, these non-native species escaped from aquaculture sites in the lower reaches of the Western Ghats rivers and have since established wild populations, thriving in their new environment. The introduction of *Labeo catla* had a profound impact on the indigenous fish fauna in Santhanur reservoir, Tamil Nadu. Historically, *L. fimbriatus* was the dominant species, accounting for 36% of the total catch in the mid-1960s. However, by the 2000s, *L. catla* had become the dominant species, contributing a staggering 80-90% to the total catch (Sugunan, 2000). The introduction of Indian Major Carps has been identified as the primary factor contributing to the decline of endemic Peninsular carps (*Cirrhinus cirrhosa*, *Labeo kontius*, *Puntius carnaticus*, *P. dubius*, and *P. pulchellus*) in numerous reservoirs of Southern India (Sreenivasan, 1996). IMCs contribute an annual landing of 12.86 t landing in the Bharathapuzha River (Renjithkumar et al., 2020). State Fisheries Department officials of Kerala argue that introducing Indian Major Carps (IMCs) through ranching does not harm indigenous species, citing their supposed inability to breed in Kerala's ecological conditions. However, local fishermen disagree, pointing out that these non-native species are already breeding in Kerala's waters, posing a significant threat to the state's endemic cyprinid fish species (Renjithkumar et al., 2020) The present report on the high landings of IMCs in Chalakudy river (6.48 t) shows a possibility of their natural expansion and creating the possibility for interbreeding between non-native/cultured stock and native/wild stock (Silas, 2010).

The exotic *Cyprinus carpio* was introduced to India to promote aquaculture development (Singh and Lakra, 2006) and was the dominant species in the landing of Chalakudy River (6.36 t). Common carp implicate environmental changes such as eutrophication through an increase in turbidity and mobilization of nutrients to the water column through its habit of rooting or digging in the bottom (Britton et al., 2007). The introduction of common carp had devastating effects on native fish populations in various ecosystems, leading to declines in iconic species such as the golden mahseer (*T. putitora*), the snow trout (*Schizothorax richardsonii*), and several carp and catfish species (Petr, 1999; Singh and Lakra, 2006; Lakra et al., 2008). Its increasing population has been found to reduce the endemic *Osteobrama belangiri* from Loktak Lake, India (Singh and Lakra, 2006). Common carp invasion causes a sharp decline in the catches of endemic schizothoracids in the lakes of Kumaon (Singh and Lakra, 2006, Lakra et al., 2008). The increasing abundance of invasive *C. carpio* has created a low landing of indigenous fish species in River Ganga (Ray et al., 2021).

The invasive, *O. mossambicus* contributed a high landing (2.94 t) in Chalakudy River compared to Bharathapuzha River (2.83 t). Roshni et al. (2016) reported that *O. mossambicus* contributed a tune of 2.59 t in the annual fish landing in Poringalkuthu reservoir, and also recorded the highest abundance index compared to other fish fauna. The introduction of tilapia had a profound impact on the reservoirs of Kerala state, with this exotic species now accounting for up to 25% of the total catch (Lakra et al., 2006). The introduction of the Mozambique tilapia has been linked to declines in indigenous fish populations in Indian waters (Bijukumar, 2000). This invasive species poses a significant threat to native fish communities globally, outcompeting them for resources, habitat, and spawning sites, and also predating on them (Russell et al., 2012). In Vaigai Reservoir, the population of *L. kontius* has been severely depleted, while *Puntius dubius* has suffered a similar fate in Amaravathy Reservoir (Sreenivasan and Sundarajan, 1967; Natarajan and Menon, 1989). Tilapia decreased the catch of *Cirrhinus reba* from 70% to 20% in Kabini Reservoir (Murthy et al., 1986). A significant diet overlap existed among the two indigenous cichlid (*E. suratensis* and *P. maculatus*) and exotic *O. mossambicus* in the Vembanad estuary, India (Roshni et al., 2021). Both *E. suratensis* and *O. mossambicus* often utilise benthic zones of the estuary, thereby exacerbating chances for food and habitat overlap (Roshni et al., 2021). The established population of tilapia in the Chalakudy River has also been found to impact the native Orange Chromide (*Pseudetroplus maculatus*) population, as both species compete for the same ecological resource (Raghavan et al., 2008b).

The introduction of tilapia has facilitated the establishment and spread of other invasive species, including Common Carp, Bighead Carp, and African Catfish, in a process known as *'invasional meltdown'* (Simberloff, 2006; Braga et al., 2018; Singh, 2021). This phenomenon occurs when multiple invasive species interact positively, enhancing each other's survival, growth, reproduction, abundance, and density, without negatively impacting one another. Nile tilapia, *O. niloticus* was introduced into open water to increase aquaculture fish production and contributed 2.47 t in the fish landing of Chalakudy River. They are voracious herbivores decreasing plant density in an aquatic ecosystem and changing the composition of native plants which can threaten many native aquatic organisms that depend on such plants for forage, protection, or spawning (Shuai et al., 2023). The invasion of Nile tilapia can decrease local biodiversity and lead to the extinction of native fish species through competitive displacement (Starling et al., 2002; Figueredo and Giani, 2005). The Nile tilapia invasion seems to induce trophic dispersion, thereby disrupting trophic positions and destabilizing the food webs of the impacted aquatic ecosystem (Shuai et al., 2023). There is often substantial diet overlap between Nile tilapia and native fishes in most tropical and subtropical countries in the world (Henson et al., 2016). Invasion of this species produces a diet shift and a decline in the trophic position of three fish piscivores in the invaded Dongjiang River, Brazil (Shuai et al., 2023). In addition to its ecological impacts, the introduction of Nile tilapia in a reservoir in northeastern Brazil has also had significant economic consequences. The invasion has led to a substantial decline in the Catch per

Unit Effort (CPUE) of commercially valuable species, indicating a decrease in the reservoir's fisheries productivity and potential economic losses for the fishing industry (Attayde et al., 2011).

The introduction of the red-bellied pacu (*Piaractus brachypomus*), native to the Amazon River basin, into India for aquaculture purposes has led to its establishment in the Chalakudy River, with a notable annual catch of 2.06 t. This species is highly adaptable and resilient, capable of thriving in diverse aquatic environments and exhibiting a flexible diet (Roshni et al., 2014; Singh and Lakra, 2011). However, its presence also poses significant concerns, as its powerful dentition can inflict serious injuries on humans and other aquatic organisms, damage fishing nets, and cause substantial economic losses to local fishers (Robins et al., 1991; Singh and Lakra, 2011). Two human deaths were reported due to Pacu attack by biting off the testicles of fishermen from Papua New Guinea (Singh, 2018) and also causes outbreaks of parasitic infestations (Moravec, 1998). These features may lead to severe habitat and trophic niche overlapping between this fish and other native fishes sharing similar ecological resources (Roshni et al., 2014). The striped catfish (*Pangasianodon hypophthalmus*), native to the Mekong and Chao Phraya River basins in Southeast Asia (Castellanos-Mejía et al., 2021), has been introduced to the Chalakudy River, where it has established a significant population, contributing 1.39 t to the catch. Its invasive nature is attributed to its high reproductive capacity, parental care, carnivorous and cannibalistic feeding behaviour, and ability to migrate long distances between ecosystems, including upstream movements to spawning habitats. These traits enable it to outcompete native species, potentially disrupting the ecosystem balance and causing ecological and economic impacts (Castellanos-Mejía et al., 2021).

The Alligator gar (*Atractosteus spatula*) a species native to the United States and Mexico (Raz-Guzmán et al., 2018), was introduced to Kerala's waters following the devastating floods in 2018, which led to the escape of the species from ornamental fish farms (Kumar et al., 2019). Although its contribution to the fishery was relatively small, at 0.1 t, this species poses a significant threat to native ecosystems. The alligator gar is a large predator, capable of growing up to 3 meters in length and weighing up to 137 kilograms (Froese and Pauly, 2022), making it a potential apex predator in its introduced range, with potentially severe consequences for native fish populations and ecosystem balance The impacts of the introduction of alligator gar on native species are unknown because only a few studies on this matter, mostly as a result of the recent introduction of this species into non-native habitats (Kumar et al., 2019). The worldwide invasion of Alligator gar suggests that invasion is at an early stage and a greater focus on early prevention and immediate response is critical (Xie et al., 2023). Considering its opportunistic piscivores, adaptations to wider ecological conditions, and large body size, precautionary methods need to be adopted and detailed research on the impacts of the introduction of the species will be carried out (Fuller, 2019).

Conclusion

The present study provides baseline information on the finfish harvest pattern in Chalakudy River in Southern Western Ghats of India. Cyprinids, cichlids, catfishes, and murrels were the major fish groups contributed in the fishery. The high contribution of alien fishes in the fishery is a serious concern to the native fish diversity in the river. The mesh size of the seine nets used in the river ranging between 8-16 mm, which goes against the mesh size regulation (>20 mm) outlined in section 6 (3) of the Inland Fisheries and Aquaculture Act of Kerala 2010. A large number of fish species caught during monsoon floodplain fishery in river causing overexploitation of many mature indigenous species (*Horabagrus brachysoma, Wallago attu, Labeo dussumieri, Channa striata* etc.) causing recruitment failure. Based on the study, it is proposed that strict legal control on the pollution, overexploitation, mesh size regulation and dispersal of exotic species is to be implemented in the river to conserve its rich biological diversity. Detailed studies regarding on the fish assemblage pattern, reproductive biology, stock assessment of indigenous species in the prevailing environmental conditions is the essential prerequisites for sustainable exploitation and management of the riverine fishery in the river.

Informed consent

Not available.

Data availability statement

Data will be made available on request.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence work reported in this paper.

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Author contributions

Chelapurath Radhakrishnan Renjithkumar: Conceived and designed the work, Methodology, Formal analysis, Writing – original draft, review & editing. Kuttanelloor Roshni: Writing – original draft, review & editing.

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RESEARCH PAPER

Exploration of *Nitzschia* from the Coastal Water of Suak Ribee, West Aceh Regency, Indonesia

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Abstract

Indonesia, a critical biodiversity hotspot, harbours diverse ecosystems. Diatoms, siliceous microalgae, are crucial in primary production and oxygen generation globally. With over 100,000 identified species, diatoms exhibit vast morphological diversity influenced by their unique cell division and life cycle. They are significant food sources for zooplankton, contributing to silica sequestration in aquatic environments and vital biological indicators of water quality, responding to environmental changes. The genus *Nitzschia*, a diverse group comprising nearly 3,000 names classified within the Sigmoideae group, has been found valuable in aquaculture due to its fatty acid content. This study isolates and identifies *Nitzschia*, a diatom from Suak Ribee Beach, West Aceh Regency, Indonesia, utilizing morphological characteristics for species identification. The research aims to contribute to understanding diatom diversity and ecological roles in this coastal environment.

Introduction

Indonesia is one of the most critical biodiversity hotspots in the world. A promising approach to identifying areas of high biodiversity is to identify ‘hotspots’ or areas determined by ‘biological commonalities’. Each hotspot features a separate biota or community of species that fit together as a biogeographic unit (Myers et al., 2000). Diatoms are siliceous microalgae of high ecological importance (Hamsher et al., 2021). Diatoms (Bacillariophyta) represent a substantial source of primary production and oxygen locally and globally. The diatom group represents a highly diverse group of algae, with more than 100,000 species identified to date (Mann, 1999; Lewis, 2007). Due to the peculiarities of diatom cell division and the life cycle, morphological diversity may frequently result from physiological differentiation. It has been estimated that they generate up to 25% to 100% of all oxygen on earth. Diatoms are a substantial food source for zooplankton and a significant component of silica sequestration in freshwater ecosystems and oceans (Minelli, 2016). They are the most effective primary producers of water in various ecosystems on earth, growing under a wide range of environmental conditions, and have become the subject of considerable attention in many countries due to their potential applications in various fields (Risjani et al., 2021). Diatoms can be utilized as biological indicators of the quality of aquatic environments (Sheath & Wehr, 2015). Diatoms in the Bacillariophyceae class demonstrate the capacity to alter their composition in response to changes in water quality, including alterations in quantity, abundance, and the presence of other taxa (Prasertsin et al., 2021).

The genus *Nitzschia*, with nearly 3,000 names, is one of the largest genera of diatoms (Kociolek, 2004). The genus *Nitzschia* A.H. Hassall 1845 is the most speciose genus within the diatom family Bacillariaceae Ehrenberg and in general is regarded as one of the most speciose among diatoms (Solak et al., 2012). *Nitzschia* species are highly resistant to lethal compounds, including organic pollutants and the most degraded industrial and municipal waters (Bates et al., 2018) most *Nitzschia* species inhabit benthic habitats (Round et al., 1990). The genus *Nitzschia* is classified within the group Sigmoideae (Hamsher et al., 2021). In addition, this pennate diatom serves an important primary role in aquatic ecosystems as a producer of phytoplankton, and as a live feed in aquaculture farms due to its high content of fatty acids (Shi et al., 2008; Pau et al., 2021).

Suak Ribee Beach is in West Aceh Regency, Aceh Province, Sumatra Island, Indonesia. It is identified as one of the beaches in the area characterized by dark-colored sand. The beach is located near residential areas, with minimal vegetation surrounding it. It is a popular tourist attraction. The most genera in this preliminary research belong to the class Bacillariophyceae. According to Fitriyah et al. (2016); Mirzaei et al. (2017), Bacillariophyceae has a high survival rate in surface-water environments. This is also interpreted by Arsad et al. (2021) as evidence that Bacillariophyceae have attachment devices, such as gelatinous stalks, which facilitate their attachment to the substrate and enable them to adapt to a range of current speeds, from 0.1 to 1 m/s.

The morphometric characteristics of frustules, which are necessary for such identification, are visible only by scanning or transmission microscopy (Arapov et al., 2017). This study aims to investigate the diatoms of the genus *Nitzschia* by isolating them from the waters of Suak Ribee Beach and identifying them based on their morphological characteristics.

Materials and methods

Time and sampling location

This study was collected in January 2023. The sampling point was located at Suak Ribee Beach, West Aceh Regency, Aceh, Indonesia with coordinates of 4°9'12.46"N and 96°6'31.82"E. The sampling in bottles was transported to the Faculty of Fisheries and Marine Science, University of Brawijaya, Malang, Indonesia. Isolation of samples was conducted at the Hydrobiology Laboratory, Department of Fish Resources, Universitas Brawijaya, and the morphological analysis using a scanning electron microscope was undertaken at the Minerals and Advanced Materials Laboratory, State University of Malang, East Java, Indonesia.

Sampling method

It is essential to select appropriate sampling sites that are proximal to discharges, accessible, and possess previous monitoring data. In this study's preliminary stage, the collection of samples from wild habitats is intended to explore the diversity of the area. Kelly et al. (2019), the sampling procedure was conducted by the standard methodology utilized in similar studies. Diatom sampling can be accomplished in a variety of ways, including the collection of samples on a substrate or sediment, by the use of a rattle to dislodge samples from rocks in the water (Solak et al., 2020), and by the sampling of water columns by using a plankton net mesh size 20 μm vertically and horizontally (Pane et. al., 2023). Additionally, samples were collected by brushing a surface area of 50-100 cm² of rock and sand sediment was transferred into the 50 mL bottles.

Figure 1. The sampling site is located in Suak Ribee, Aceh, Indonesia.

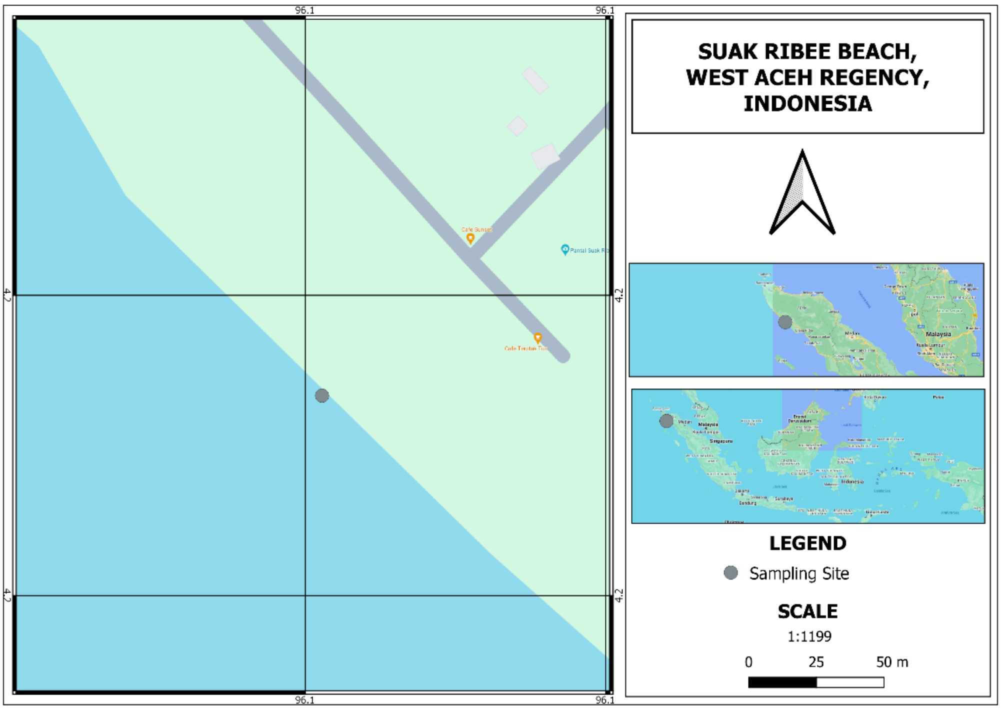

Figure 2. The mapping of the sampling locations for this study.

The initial activity was sterilization, which aimed to eliminate unwanted microorganisms (contaminants) from tools and containers used for diatom cultivation. The equipment, including test tubes, erlenmeyers, and aeration hoses, was soaked in a chlorine solution at a dose of 1 mL per 1 L of water. The solution was allowed to act for 24 hours, after which the equipment was rinsed with clean water and dried. The medium utilized in this research is seawater. From the isolation stage onwards, this medium was employed to maintain stable culture environment conditions. The medium was treated using the standard method or pure culture, achieved using F/2 Walne fertilizer and vitamin B12. The axenic culture begins with preparing erlenmeyer flasks, which were of the requisite size of 250 m and prepared in triplicate. The inoculants that have been prepared are then included in the erlenmeyer flasks. Accordingly, the pure cultures required development through the repetition of transfer steps. The optimal temperature for diatom culture was 24 °C, maintained by a fluorescent lamp at a distance of approximately 30 cm. Jiang et al. (2020), in order to ensure the continued cultivation of the diatom biomass, it was necessary to expand the scale of production. The initial diatom culture stage should be prepared in the log growth phase. The harvesting of diatoms should commence when they begun to detach from the substrate, typically around 6-7 days. Centrifugation of the culture should be employed to collect the diatom biomass as a preservation method before SEM identification.

Identification

The observed characteristics were identified through morphological diversity. The text identifies and provides the referenced literature for each species' description. Secondary data on local and similar records were collected and compiled from previous studies and books. The morphological characteristics of the diatom isolate were then identified through descriptive analysis using the diatom identification books Davis (1955), Prescott (1970), Witkowski et al. (2000), and diatoms.org.

Scanning Electron Microscope (SEM)

Scanning Electron Microscopy (SEM) was performed using a Merk FEI instrument. The Inspec-S50 is a device that allows for the inspection of materials at the nanoscale. The sample to be analyzed was positioned on a holder with a precision of ±10 mm. Samples were used for analysis using an Au-Pd coating to enhance conductivity. The sample was subsequently inserted into the SEM chamber and then subjected to vacuum pumping. Once the chamber was completely evacuated, the SEM machine was ready (beam on).

Results and discussion

Description

The genus *Nitzschia* has several species with different characteristics. These genera present variations in valve width, presence or absence of a central interspace, fibula and stria density, and other features that distinguish these species. Oliver et al. (2021), the genus *Nitzschia* includes a diverse range of species with varying cell sizes, with the majority falling within the range of 5–70 µm in length. Based on morphological identification, *Nitzschia*, a diatom species initially collected from coastal waters in Suak Ribee, West Aceh Regency, Aceh, Indonesia, was isolated in axenic culture by ALGAEn. The isolate is euryhaline and capable of cultivation in seawater and low-salinity brackish water, with the ability to grow using a CO_2 supply.

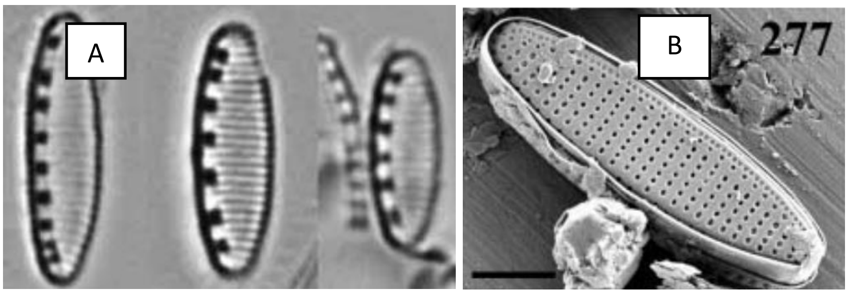

Figure 2. A. The micrograph of *Nitzschia soratensis*, obtained from the Sorata Department in Bolivia, ANSP GC 26804 (Trobajo et al., 2013); B. The SEM image of *N. soratensis* with the scale bars 2 and 5 µm (Morales and Vis, 2007).

Determining species based on cellular morphology can be challenging within the genus *Nitzschia* (Figure 4). The examined strain exhibits similarities to *Nitzschia soratensis* (Figure 3) (Morales and Vis, 2007; Trobajo et al., 2013; Hamsher et al., 2016; Puccinelli et al., 2019). The isolate exhibits larger valves that are linear or parallel sides, becoming elliptical in smaller specimens. The apices are broadly rounded. The frustules are rectangular in girdle view with the canal raphe and fibulae relatively large. Round et al. (1990), a fibulae is defined as an internal bar or silica strut that supports the raphe canal. In the plural form, the term "fibulae" describes these structures. The fibulae transapically extend from the valve face to the raphe canal. Genera known to contain fibulae examples include *Denticula*, *Nitzschia*, and *Surirella*. Striae are present in the centre of the valve and are arched near the poles, a feature that is particularly evident in smaller cells. Areolae are visually present in some larger specimens. Valve length 8.0 µm and valve width 3.0. In terms of length, the specimen in question measures 8,247 µm, while its width ranges from 2 to 3 µm (Figure 4).

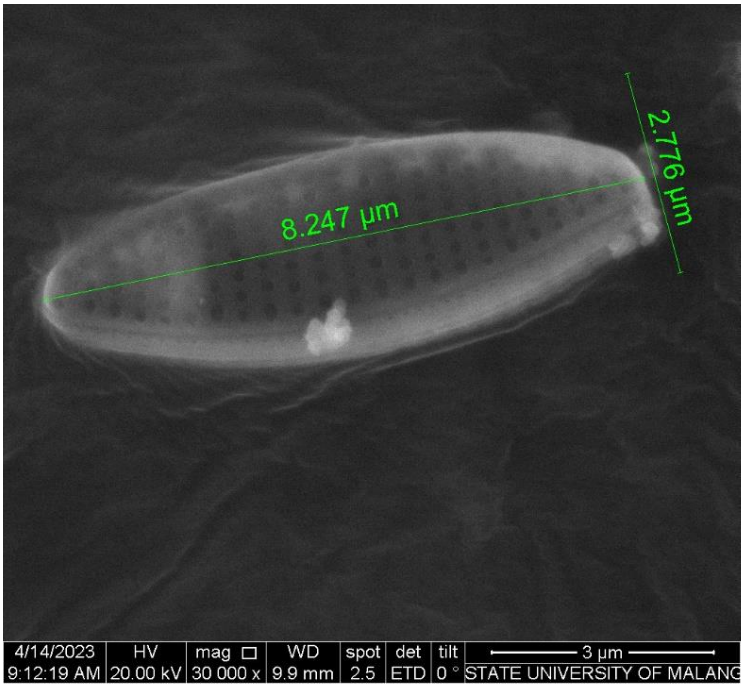

Figure 3. SEM of *Nitzschia* isolated from Suak Ribee Beach.

Nitzschia cells are typically elongated in shape, either linear or lanceolate, and *Nitzschia* species may exist as solitary cells or in colony form. Most *Nitzschia* species have two chloroplasts in each cell, one at the anterior end and one at the posterior end. Each valve has a raphe that is eccentrically positioned and supported by fibulae. The two raphe structures of a frustule are diagonally opposite, which is a defining characteristic of the genus (Nitzschioid) (Lundholm and Jvind Moestrup, 2000; Carballeira et al., 2017; Solak et al., 2021). The number of striae and fibulae on the valve can differ between *Nitzschia* species. One study reported 15 fibulae and 31 striae per 10 µm in a potentially new *Nitzschia* species (Louw et al., 2018). The identification of species to their respective taxonomic levels remains a challenging endeavor due to the vast array of species present.

Distribution

A number of species belonging to the genus *Nitzschia* are found in a wide variety of marine habitats, from the equatorial to the polar regions (Cipolletta et al., 2022). The vertical distribution of phytoplankton species is influenced by both environmental factors, such as the physical structure of the water column, irradiance, and nutrient availability, and biological characteristics of the species, including the presence of flagella, the capacity to regulate buoyancy, and adaptation to low light environments. Nevertheless, phytoplankton are capable of accumulating and even growing in subsurface chlorophyll maxima, and in correspondence with density gradients, where they can form thin phytoplankton layers (Durham and Stocker, 2012). The geographical distribution of certain species of Pseudo-nitzschia is limited to specific regions, which are classified as tropical, temperate, or cold-water species (Teng et al., 2012).

However, our isolate is considered a tropical species. It is very rare to study *Nitzschia* in this area, particularly in Suak Ribee, West Aceh Regency, Aceh, Indonesia. Risjani et al. (2021) identified the highest abundances of *Nitzschia frustulum* (6,8%) and *Nitzschia inconspicua* (4,9%) on the east coast of East Java. These were observed on the beaches of Tiga Warna, Watu Pecah, Clungup, and Gatra. Rachman and Thoha (2021), the Pseudo-nitzschia pungens species, identified in the Lampung Bay area, was given the LMP3 label. According to Lelong et al. (2012), it can be generally observed that Pseudo-nitzschia is frequently found in high density at a warm temperature, high salinity, and interestingly, in low nutrient concentration. Lampung Bay is situated in the southeast of the island of Sumatra, with its coastline facing the Sunda Strait, which separates the island from the Indian Ocean.

Potential Implication

The study of *Nitzschia* in the coastal waters of Suak Ribee, West Aceh Regency, Indonesia, can have considerable implications based on the present research, which has shown that morphological surveys can assist in clarifying the taxonomy of *Nitzschia* species, which is key to understanding their ecological roles and evolutionary relationships. This is particularly important for species that are difficult to distinguish based on morphological features. López-Urrutia and Morán (2015), the composition and size structure of phytoplankton can influence primary production rates, thereby impacting the overall energy flow within ecosystems. In addition, variations in phytoplankton community structure can impact the biogeochemical cycling of carbon and other elements, influencing nutrient dynamics within the ecosystem. It is known that certain species of *Nitzschia* produce the neurotoxin domoic acid, which can lead to amnesic shellfish poisoning in humans and mass mortality of wildlife. This includes species within the related genus Pseudo-nitzschia. According to Delegrange et al. (2018), identifying Pseudo-nitzschia and their association with domoic acid levels highlight the significance of implementing monitoring programs for harmful algal blooms (HABs) and toxin production. Regular monitoring can detect the emergence of HABs at an early stage and assess the risk to marine ecosystems and human health.

Conclusion

The Nitzschia genus is known to exhibit a diverse range of species with distinct characteristics. These characteristics include variations in valve width, the presence or absence of a central interspace, fibula and stria density, and other features that distinguish these species. The study of Nitzschia species in the coastal waters of Suak Ribee, West Aceh Regency, Sumatra Island, Indonesia, can provide valuable insights into environmental monitoring and management in the region.

Informed consent

Not available.

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Conflicts of interest

There is no conflict of interests for publishing their study.

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Author contributions

Elya Putri Pane: Writing original draft, Conceptualization, Data curation, Formal analysis, Yenny Risjani: Supervision, Investigation, Methodology, Writing original draft, Yunianta: Superivision, Validation, Methodology, Review, Mehmet Kocabaş: Project administration, Review, Editing, Gilang Drajat Maulana: Formal analysis, Investigation, Luvi S. Handayani: Editing, Review.

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RESEARCH PAPER

Fish diseases and health investment needs for the aquaculture sector in Kenya

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Abstract

Aquaculture plays an important role in the provision of food, livelihood and source of income in Kenya. There is a rapid shift from extensive methods to semi-intensive and intensive culture methods with the potential to produce higher output. However, intensification in aquaculture comes with risks of diseases. In recent years, there has been an increase in emerging and re-emerging diseases in aquaculture. Increased occurrence of diseases in aquaculture production systems leads to reduced profits, affecting the social and economic sustainability of aquaculture. To mitigate the negative impact of fish diseases in aquaculture, rapid discovery, characterization, and diagnosis of causative agents and risk factors are crucial for the development of effective control measures. There is need for investment in skilled personnel/researchers, well-equipped and dedicated laboratories, routine surveillance, development of relevant prophylactics, biopesticides and chemo-therapeutants, quarantine facilities. Furthermore, developing the institutional capacity governing aquatic animal health issues and improving the linkages between various stakeholders in the aquatic animal health issues nationally and beyond will be critical in improving fish health and disease control in the aquaculture sector in Kenya.

Introduction

Aquaculture plays a crucial role in meeting the global rising need for high-quality protein derived from animal sources. About 49% of the world's fish production comes from this sector, which has been growing recently (FAO, 2022). Over the past decade, Kenya's aquaculture output has nearly doubled, improving the nutritional status of vulnerable groups, creating job opportunities, increasing income, and fostering economic growth in rural areas (Cheserek et al., 2022). Aquaculture production grew from 12,152 tonnes in 2010 to 22,140 tonnes in 2022, making up 12.7% of the nation's total fish production (KNBS, 2023). However, intensification in aquaculture comes with the risk of disease. Aquaculture has a higher risk of disease than capture fisheries since diseases can spread quickly among aquatic animals raised at high densities in confined environments (Walker and Mohan, 2009). Additionally, new channels for the cross-border spread of aquatic animal diseases have been created due to globalization and the rise in the volume of international trade in aquatic organisms and their associated goods (Rodgers et al., 2011). Furthermore, there's a chance that aquaculture operations in the tropics could eventually have higher cumulative mortalities and quicker disease transmission, and this will probably be made worse by climate change, causing the emergence of more virulent pathogens (Cascarano et al., 2021).

Fish producers in Kenya have suffered enormous losses, ranging from 40% to 100% of the fish in both ponds and cages (Aura et al., 2018; Njiru et al., 2019). This situation deters aspiring farmers from entering the farming industry. Disease outbreaks can have an adverse effect on the economy because they cause significant losses for many fish farmers (Opiyo et al., 2018). This could have an impact on the amount of fish produced, the market supply, and the accessibility of high quality, nutrient-dense fish (Alfred et al., 2020). Fish disease outbreaks raise the cost of production owing to the money lost from fish mortalities, the expense of treatment, and the reduced growth of the fish during recuperation (Alfred et al., 2020). However, aquaculture and international trade will continue to grow despite the potential risks of diseases.

Therefore, as fish farming expands globally, it is necessary to create comprehensive health management practices that include identifying the cause of diseases, enhancing disease monitoring, developing novel approaches for diagnosing diseases, creating efficient and innovative vaccines and antiviral medications, and utilizing current technologies to manage fish diseases (Akoll & Mwanja, 2012; Syanya & Mathia, 2023). For the implementation of the measures outlined above, this paper provides insights on the disease status of aquaculture fish and fish health investment needs for the aquaculture sector in Kenya.

Materials and Methods

In order to produce a thorough review of the aquaculture fish diseases and fish health investment needs in Kenya, a narrative review approach was used. The review focused on the status of fish diseases in the Kenyan aquaculture sector, their socio-economic impact in the aquaculture sector, management challenges and solutions to fish diseases, and investment needs to improve fish health in the aquaculture sector in Kenya. To this end, a wide range of phrases (closely related to fish diseases) were searched in the scholarly platforms of Science Direct, Research Gate, Google Scholar, and Web of Science. A literature review was done from 40 research publications that satisfied the requirements of this study. The review process is summarized in Figure 1.

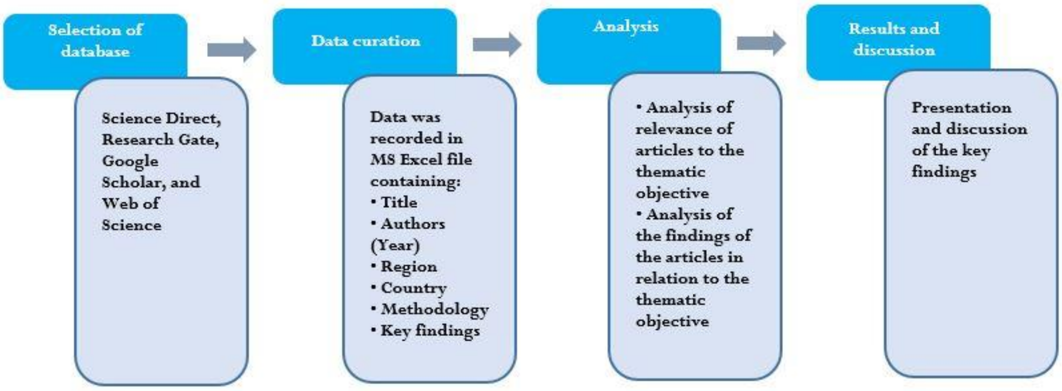

Figure 1. Flowchart of the review process of the fish diseases and fish health investment needs for aquaculture sector in Kenya

Results

Fish disease status in the Kenyan aquaculture sector

Very limited information exists on disease occurrence in the Kenyan aquaculture sector. Most studies on fish health have focused on parasites in the two most cultured species, *Oreochromis niloticus* and *Clarias gariepinus* (Akoll & Mwanja, 2012; Ochieng et al., 2012; Opiyo et al., 2018), focusing on the parasite descriptions, biology and pathology. The dearth of information regarding fish diseases may be attributed to several factors, including inadequate diagnostic facilities, a shortage of personnel with experience in fish health, high diagnostic costs, a lack of veterinary laboratories equipped to identify pathogens, a lack of disease outbreak reports as a result of farmers' poor documentation, and the socioeconomic status of the farmers (Akoll & Mwanja, 2012). On the other hand, some farmers have reported fish deaths on their farms, with fish mortalities ranging from 40 to 100% in ponds and cages (Aura et al., 2018; Njiru et al., 2019). Although this is typically linked to issues with water quality, since no diagnosis is made at the farm level to rule out infections, it is possible that the mortalities are health-related. The majority of small- and medium-scale farmers don't bother determining the reason for fatalities, and when they do, they seek advice from universities, or fisheries officers, who are likewise poorly informed about fish health (Akoll & Mwanja, 2012). According to a 2014 study, the majority of the fish stocks in certain hatcheries were lost due to bacterial and fungal infections (Njagi, 2016). The small-scale hatcheries were found to experience more mortality due to insufficient biosecurity measures and subpar infection control procedures. The majority of diseases in fish farms that are documented are fungal, primarily saprolegniasis (Figure 2), and bacterial, mostly haemorrhagic and pop eye diseases (Akoll & Mwanja, 2012; Walakira et al., 2014).

Streptococcus iniae has been found in some hatcheries (Figure 3) causing infection in the fish, particularly the freshly stocked fish larvae, which often display a C-shaped curvature (Florio et al., 2009; Walakira et al., 2014). Grow-out *O. niloticus* have also been affected by fish lice (*Argulus* spp.), while *C. gariepinus* have been affected by freshwater white spot disease (*Ichthyophthirius multifiliis* (Figure 4) (Njagi, 2016). Disease occurrences in farms have been attributed to poor management practices such as the use of on-farm formulated feed with high bacterial load, and the use of untreated water directly from the source (Njagi, 2016, Walakira et al., 2014). In most cases, water is used straight from a river or stream, introducing high bacterial loads that impact younger fish more than adults, indicating substandard hatchery operations used in Kenyan aquaculture sector (Njagi, 2016). The common bacterial infections affecting pond fish cultured in Kenya are caused by *Aeromonas hydrophila*, *Pseudomonas fluorescens* and *P. aeruginosa*, *Edwardsiella tarda*, *Flavobacterium columnare*, *Mycobacterium fortuitum* and *S. iniae* (Akoll & Mwanja, 2012). Signs of bacterial and fungal infections have been observed in cages including fin rot, cloudy eyes, and skin sores (Aura et al., 2018), as shown in Figure 5.

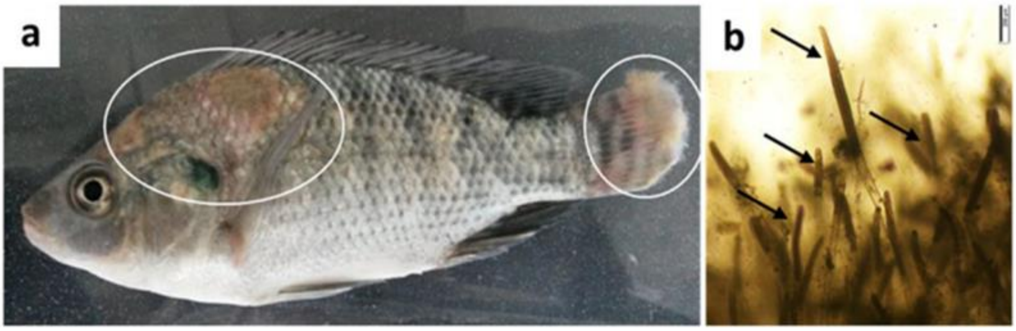

Figure 2: (a) Nile tilapia showing clinical signs of Saprolegniasis, white to grey patches on the external body surfaces and tail. (b) Microscopic examination of wet mount preparation of *Saprolegnia* showing characteristic aseptate hyphae and zoosporangia (arrows) (Elgendy et al., 2023).

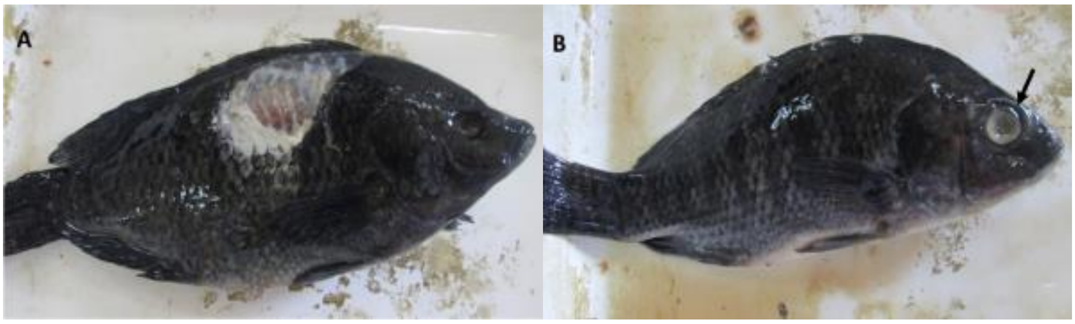

Figure 3: Photograph showing a skin ulcer (A) and corneal opacity (B) from a field outbreak of streptococcosis in tilapia (*Oreochromis niloticus*). Arrow points to a sunken eye, another common finding (Bwalya et al., 2020).

Figure 4: White spots on the skin of a catfish caused by *Ichthyophthirius multifiliis* (Durborow et al., 2015).

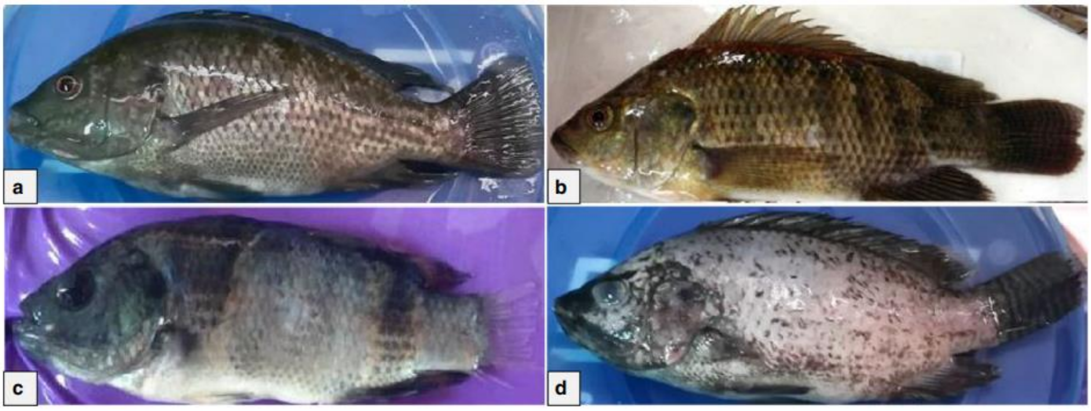

Figure 5: Nile tilapia showing gross signs of (a) cutaneous haemorrhages; (b) irregular scale loss and dark discoloration; (c) severe scale loss and fin rot and; (d) peeled skin (Rao et al., 2021).

Socio-economic impact of fish diseases in Kenya's aquaculture sector

The aquaculture sector, like other farming systems, is faced with the challenge of disease caused by viruses, bacteria, fungi, parasites and other undiagnosed and emerging pathogens (Alfred et al., 2020). Fish disease is one of the bottlenecks impacting the commercialization of the aquaculture industry in Kenya, thus impeding both economic and social development (Munguti et al., 2021a). Although little information is available in the scientific literature, Bondad-Reantaso et al. (2005) noted that fish diseases in aquaculture can have significant and varied socio-economic impacts which include and are not limited to:

a) Loss of income and livelihoods- fish diseases can cause significant financial losses to aquaculture farmers, especially smallholder ones who mostly rely on aquaculture for their livelihoods. Fish mortality due to disease infection reduces the farmer's stock and, consequently, their income.

b) Food insecurity and malnutrition- aquaculture plays a critical role in the provision of protein-rich diet among most communities in Kenya. Therefore, fish disease outbreak reduces the availability of fish for consumption, leading to food shortages and potential malnutrition, particularly among vulnerable populations like children.

c) Loss of employment- the aquaculture industry creates employment opportunities along the value chain, including farm workers, processors, distributors, and retailers. The outbreak of fish diseases can disrupt these employment opportunities, leading to job losses and decreased economic activity in affected communities.

d) Decreased investment and market confidence- frequent outbreaks of fish diseases can discourage investors and development partners from funding aquaculture projects due to the perceived risks involved. The decreased investment can stifle the growth of the aquaculture sector and hinder its potential to contribute to the country's economic development.

Fish disease management challenges and possible solutions in Kenya's aquaculture sector

Challenges

Health services in aquatic animals are comparatively underdeveloped as compared to health services in terrestrial animals (Peeler & Taylor, 2011; Scarfe & Palic, 2020). There is a dearth of information about disease outbreaks in fish farms in Kenya. The knowledge gap is caused by a number of factors, including inadequate diagnostic facilities, a shortage of personnel with experience in fish health, high diagnostic costs, a dearth of veterinary laboratories equipped to identify pathogens, a lack of outbreak reports as a result of farmers' poor record-keeping, and the socioeconomic status of the farmers (Akoll & Mwanja, 2012; Opiyo et al., 2018). According to Akoll and Mwanja (2012), inadequate fish health services in Kenya are caused by the misconception that fish do not become sick. However, this belief is beginning to change in

Kenya and other developing countries where fish disease outbreaks have had catastrophic effects on the economy (Syanya & Mathia, 2023; Zornu et al., 2023).

Possible solutions

Some of the ways fish farmers can overcome disease management challenges in Kenya, as discussed in this section, include proper nutrition and stocking density, implementing best management practices, selective breeding, surveillance and monitoring, vaccines administration and implementing biosecurity measures.

Proper nutrition

Despite significant progress in understanding fish's nutrient requirements, issues related to dietary imbalances continue to affect farmed fish (Syanya et al., 2023). Providing fish with an appropriate diet is crucial for their general health and well-being, in addition to promoting growth and preventing nutritional deficiencies (Bandara, 2018; Munguti et al., 2023).

Fish farmers should thus make sure that their fish feed is properly stored in a dry, cool environment. This is significant because moldy feedstock can harbor *Aspergillus flavus*, which can produce aflatoxins that are detrimental to fish and, to a lesser extent, humans (Syanya et al., 2023). In order to prevent the spread of infections to healthy fish, fish farmers should also refrain from feeding fish with fish waste and viscera. Such feed may weaken the fish's immune system and prevent them from receiving a nutritionally balanced diet, leaving them more susceptible to pathogenic diseases (Syanya et al., 2023). Additionally, hygienic dry pellet diets with the right amount of vitamins and minerals added should be utilized to improve fish immunity and growth (Bandara, 2018).

Proper stocking density

The health of fish relies on maintaining the proper stocking density. Fish farmers must ensure that the number of fish in the culture system is appropriate and does not lead to stress or overcrowding (Syanya et al., 2023). Overstocking can cause cannibalism because of competition for food, in addition to causing skin injuries. The skin serves as the main defence against viruses; any damage to the skin can facilitate the entry of pathogens (Wanja et al., 2020). Furthermore, overstocking in intensive systems causes fish faeces to accumulate, which increases ammonia levels in the water and results in poor water quality (Jobling et al., 2011).

Implementing best management practices

Farmers can prevent disease outbreaks by implementing best management practices. This entails keeping the pond environment clean by managing silting, plants, and the right balance of phytoplankton and zooplankton, as well as guaranteeing good water quality in the culture system (sufficient water and dissolved oxygen, and free from pollutants) (Wanja et al., 2020; Belfiore et al., 2021). Other practices include preventing stress in fish by managing stocking density, separating different-sized fish to prevent fighting, offering sufficient food supply, and treating the fish with care (Weitzman et al., 2021; Syanya et al., 2023). Additionally, farmers should keep disease-causing organisms out of canals and ponds by eliminating wild fish and using screens to block their access, regulating predators (birds and mammals), and routinely sanitizing ponds to eliminate disease organisms and their intermediate hosts (Wanja et al., 2020; Kumar et al., 2021). Other practices include avoiding mixing water among ponds, and, in the event of a disease epidemic, removing sick fish and burying diseased fish with quicklime away from the culture facilities (Kyule et al., 2022).

Selective breeding

There is a great deal of opportunity to select for enhanced resistance to important diseases because disease resistance is nearly always heritable (Houston, 2017). Since disease resistance is nearly always heritable, selective breeding can be utilized as a potentially effective way to control diseases (Megahed, 2019). Heritable qualities that can be enhanced by selective breeding for long-term genetic gain and trait enhancement include body weight, survival, and disease resistance (Abwao et al., 2023).

Surveillance and monitoring

Timely detection of disease outbreaks will help to stop infections from spreading and lower fish mortalities. While aquaculture production has intensified in Kenya, there hasn't been a corresponding increase in the adoption and implementation of advanced management strategies for disease control, prevention, and monitoring. This has left aquaculture vulnerable to numerous disease outbreaks, including bacterial, viral, fungal, and parasitic incidents (Kyule et al., 2022).

Vaccine administration

Improving vaccination is one of the most critical and perhaps the most effective methods for preventing and controlling infectious diseases in fish aquaculture (Assefa et al., 2018). Currently, there is no information available regarding Kenya's regulations regarding the use of probiotics, antibiotics, and vaccines in aquaculture (Opiyo et al. 2018). A study by Syanya & Mathia (2023) reported that there have not been any cases of the use of vaccines in Kenya’s aquaculture production units.

Implementing biosecurity measures

In a controlled aquatic environment, a higher percentage of fish infections (90%) are linked to inappropriate husbandry techniques and insufficient implementation of biosecurity measures (Wanja et al., 2020). Biosecurity is a set of management techniques that minimize the likelihood of pathogenic microbes infiltrating areas (Huber et al., 2022). Sanitation and disinfection are two important biosecurity practices that should be paired with pathogen-free seed selection and targeted treatments to either completely eradicate or significantly reduce infections to non-infectious levels **(**Dewulf & van Immerseel, 2019)**.**

Although not well established, implemented biosecurity measures in Kenya’s aquaculture systems include limiting visitors’ movement in the hatchery, cleaning of culture units, stocking of disease-free broodstock, use of protective clothing, disinfection of equipment, use of foot baths, use of good water quality on the farm, and water temperature maintenance (Syanya & Mathia, 2023).

Investment needs for fish health management and disease control in Kenya’s aquaculture sector

Some of the suggested investments to improve fish health and disease control in the aquaculture sector in Kenya include and not limited to:

Investment in skilled personnel/researchers

Fish health issues have received little attention or documentation in Kenya up until recently, with the majority of studies concentrating on parasitic diseases. Though small advances have been made in that direction, a review by Akoll & Mwanja (2012) indicated that there was very little research on bacterial, fungal, and viral infections in the region. The paucity of outbreak reports due to inadequate record keeping, the high expense of detecting and identifying such infections, and the lack of diagnostic infrastructure were all cited as contributing factors. This finding holds to this day (Syanya & Mathia, 2023). As a result, funding for the education and training of fish health specialists is required to deal with issues related to disease diagnosis, treatment, and the appropriate use of medications in the sector.

Investment in research on development of relevant prophylactics and chemo-therapeutants

Chemotherapeutants are frequently used in pond culture in Kenya to treat a wide range of illnesses (Opiyo et al., 2020). Even while biotherapy has undergone a number of experiments in the lab, it is not yet feasible to apply such treatments widely (in the culture systems) (Huo et al., 2024). As a result, greater funding is needed to develop preventatives for widespread use in the field. Furthermore, a closer examination of some of the medications used, such as formalin (a carcinogen used to treat a range of ectoparasite illnesses), highlights the pressing need to create safer alternatives for both farmers and consumers (Munguti et al., 2021a).

Investment in well-equipped laboratories

There is need of having well-designed and equipped laboratories in Kenya, especially in light of the growing investments in aquaculture. For instance, the World Organization for Animal Health has not yet accredited Kenya's specialized fish diagnostic facilities (Opiyo et al., 2018).

Investment in the institutional capacity governing aquatic animal health issues

Legislative and policy instruments must be repositioned to take aquaculture development into account, which considers concerns about the health of aquatic animals (Akoll & Mwanja, 2012). Regulation of drug application in aquaculture is necessary to avoid issues of environmental residue and the ensuing drug resistance (Defoirdt et al., 2011).

Investment in routine surveillance

The creation and execution of regular surveillance and monitoring programs for aquatic animal diseases are essential. This is due to the fact that surveillance makes it feasible to identify diseases long before they cause significant losses (Matolla, 2019). Enhancing biosecurity governance, expertise in fish disease pathology, diagnostics, surveillance, emergency preparedness, and networking assistance for aquatic animal health management are all necessary.

Investment in quarantine facilities

The globe is believed to have become a global village recently, with a great deal of trade occurring worldwide. Opiyo et al. (2018) pointed out that in Kenya, there are no quarantine facilities and only rudimentary biosecurity measures are in place for the monitoring of new imports. Therefore, there is a chance that exotic diseases will be introduced into Kenya's systems as a result of the transfer of fish fry and brooders from other nations, which could lead to the spread of infections and diseases through the movement of live fish. The lack of infrastructure for quarantine and the infrequent risk analysis procedures applied to the trade in live aquatic animals raise the possibility of disease infections spreading quickly both within and across nations if these practices are maintained (Bondad-Reantaso, 2005; Akoll & Mwanja, 2012). Therefore, investment in the quarantine facilities will be critical to curb the above risks.

Investment towards improving the linkages between various stakeholders in the aquatic animal health issues nationally and beyond

Most research findings are not available to the fish farmers due to the weak linkages between research and industry (Munguti et al., 2021b). Building capacities and establishing organizations or cooperatives that can help address aquatic animal health issues can be achieved through investing in the strengthening of relationships between various sectors working in the animal health aspects. Additionally, funding local officers' training and capacity building can greatly aid in raising understanding of how to address aquatic health-related issues.

Conclusions

Fish health issues have received little attention or documentation in Kenya’s aquaculture sector. It is important to adopt a multi-disciplinary approach that utilizes a combination of techniques to fully understand the biology of emerging and re-emerging diseases in aquaculture. To improve aquaculture production, and the ability of aquatic species to adapt to changing health issues, a comprehensive approach that includes all components of the epidemiologic triads is required for aquatic health management. Additional research and efforts in this field should continue to explore the intricate interactions between the host, pathogen, and environment, aiming to develop tailored strategies and solutions to address the unique needs and challenges of different aquatic species and habitats. Fisheries extension personnel, researchers and veterinarians need to have adequate background information on aquatic animal disease and health management to understand the problems and needs of the fast-growing aquaculture industry in Kenya. There is a need to enhance awareness of the importance of health management in the aquaculture industry through education and information dissemination.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical approval

There were no human or animal subjects used in this study. Therefore, no ethical approval was needed.

Informed consent

Not available.

Data availability statement

There was no data used in the present study.

Funding organizations

No funding available.

Author contributions

Jonathan Munguti: Conceptualization; Writing - original draft, **Jimmy Mboya**, **James Kirimi, Domitila Kyule, Jacob Iteba**: Writing - original draft, Writing - review & editing. **Esther Magondu,:** Writing - review & editing, **Kevin Obiero**: Writing - original draft; Writing - review & editing, **Elick Otachi**, **Florence Thiakunu, Kevin Ouko, Mary Opiyo**: Validation; Writing - review & editing

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