JARSFM- Journal of Aquaculture Research and Sustainable Fisheries Management
Volume 2, Issue 2 | September -2025
e-ISSN: 3067-0713 Print ISSN: 3067-0705

Evaluation of the Effect of Floating Cage Design on Growth and Stress Response on Rainbow Trout in Alpine Reservoirs

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Received: 11-07-2025; Revised: 30-07-2025; Accepted: 18-08-2025; Published: 04-09-2025

Abstract:
Cage design (Floating cage) is an important aspect of water flow, distribution of oxygen and fish health in open-water fish farming. The study involved the evaluation of the effectiveness of two floating cage systems, i.e., standard square cages and semi-circular V-shape cages that could be deployed in rearing Rainbow Trout (Oncorhynchus mykiss) at a high-altitude reservoir and they operated over a 10 week period. A higher specific growth rate of 9.2 % was recorded in the V-shaped fish cages than in the square cages of fish, implying better growth conditions as a result of the good water flow and oxygen distribution. Also, plasma cortisol concentration, a stress indicator was lower in fish in V-shaped cages depicting low levels of stress. The amount of dissolved oxygen was steady greater in the V-shaped cages owing to increased flow of water. It has been found that the operational costs of the two designs of cage were similar after carrying out a cost-benefit analysis. The results confirm that some engineering design modifications of cages could substantially provide better welfare and lower stress, growth of fish, by far at a cheaper cost of making the coldwater aquaculture systems to work in the best possible way.

Keywords: ***Floating cage design, Rainbow trout, Oncorhynchus mykiss, v shaped cages, water flow, fish welfare, growth performance, stress response, coldwater aquaculture.***

1. Introduction

1.1 Background of Rainbow Trout and Coldwater aquaculture

Coldwater aquaculture the cultivation of water animals under cold climatic condition where temperatures normally remain between 5 to 18 C degrees. This area is vital in the multiplication of quality fish in colder areas of the globe, either on high altitude or northern latitudes. Rainbow Trout (Oncorhynchus mykiss) is one of the most common species that has been grown by cold water aquaculture systems, and this is a cold water fish indigenous to North America and its cultivation has been promoted by a combination of its high market demand and rapid growth.

Rainbow Trout are usually kept in open-water farms like extend-net-cages in lakes, reservoirs and rivers where the environment can be changeable in terms of water temperature, oxygen, and water quality. These factors have a significant impact on their growth performance, general health and on the structure features of the rearing system.

1.2 The Contribution of Cage design to Growth and Welfare of Fish

Floating cage design is very important to achieve an appropriate control of the environment inside the aquaculture systems. The design of the cages determines water circulation, the distribution of oxygen, and waste removal, which are vital contributors to the proper growth and the health of fish. In floating cage cultures the water quality is directly independent on the movement of water around the cage and the distribution of oxygen in the tank which influences the stress response and the feeding efficiency of the fish.(1)

In aquaculture, most of the cages are used in a form of the traditional square or rectangle, but recent research indicates that cages constructed in semi-circles and V-shape may have better water flow and oxygen distribution. Such enhancements should lead to enhanced growth rates, low levels of stress, and a more favorable environment all of which the fish will enjoy. The modified shape of the cages might therefore offer an effective yet simple remedy towards the improvement of fish welfare and growth potential, especially in coldwater system where there are more subjection of environmental vagaries.

1.3 Research and study gaps Research Rationale

Although the influence of other types of cages on the fish growth and welfare was investigated in previous research, the direct effect of the V-shaped cages on Rainbow Trout that is produced in coldwater aquaculture systems has been insufficiently reviewed. The existing studies have concentrated more on the alterations in cage design concerning the species of marine fish or warm-water aquaculture and there is a denying gap in research

when addressing the same area but in high-altitude, coldwater conditions. Moreover, although water quality and oxygenation have been investigated in detail, they should be related further to the stress hormonal concentration (i.e., cortisol) and general welfare of the coldwater fish species such as Rainbow Trout.

Since there is growing interest in enhancing fish welfare and growth efficiency on coldwater systems, such a study may fill the gap by comparing performance of the standard square floating cages to semi-circular V-shaped ones. In that way, this study will be able to give some information on how engineering adjustments may benefit the Rainbow Trout on their growth, stress response, and oxygen distribution.

1.4 Purpose of the Current Paper

This research will aim at the following:

- To compare the growth performance of Rainbow Trout grown in V-shaped cages with conventional square cages in a 10 weeks time.
- In order to determine the stress reaction of fish in both types of cages by measuring the plasma cortisol levels.
- To evaluate the concentration of the oxygen in solution and the circulation of water in the two cage systems with references to the effects of the cage design on the quality of water.
- To carry out a cost-benefit analysis of the V-shaped cage and the regular square cage, assessing operating costs and general feasibility to aquaculture systems.

The proposed objectives will therefore show how recognition of factors behind changing fish welfare and growth efficiency through simple engineering modifications to cage design can lead to more efficient fish production that has a wider implication to enhance the sustainability and productivity of coldwater aquaculture systems.(2)

2. Methods and Materials

2.1 Test Site and Geographical Figures

An experiment was carried out at one of the high altitude alpine reservoirs, at about 1,500 meters above the sea level in a temperate climatic zone. The characteristics chosen reservoir has a coldwater environment that is ideal in rearing Rainbow Trout (Oncorhynchus mykiss). The study site was characterized by naturally varied water temperature, observed to be between 10 o C and 14 o C during the 10 weeks duration of the trial process. Water quality parameters were thoroughly observed during the experiment since the water quality with regard to oxygen, pH, and ammonia concentration must not be extreme to cause poor fish health. The reservoir water was supplied by a local stream that would create a constant supply of fresh water into the cages.(3)

2.2 Floating Cage Systems Characterization (Square and V-Shaped)

In this study two types of floating cages were employed:

1. **Standard Square Cage**: This is the usual design that has a rectangular casing with four vertical sections in addition to a mesh net that enables the water to flow around the fish. Dimensions of the square cages used to raise these cat fishes was 3 meters x 3 meters (depth 3 meters) and the volume was 27 cubic meters. It is a common structure in the aquaculture systems because of the complexity of design and installation.
2. **V shaped Cage:** Semi-circular shaped V-shaped cage had an experimental change of design to enhance water flow and distribution of oxygen. The cages were similar to that of the square cages (3 meters x 3 meters and 3 meters deep) except that they were designed with a sloping mesh structure, which forms a V-shape. The design also made it possible to circulate water more through the bottom of the cage enabling the process of exchange of oxygen and efficient removal of wastes. The V-shape cages were supposed to offer a more even distribution of water in the system, avoiding low oxygen areas.

2.3 Stocking and management Practices

One hundred and fifty Rainbow Trout were stocked in every cage system, and no more than 75 Rainbow Trout per cage were employed so that the stocking density might be constant thereby reducing overcrowding. The fish used was of good quality and obtained in a reputable hatchery, with initial weights of 45 +/-3g on average. The stocking density was maintained at around 10 fish/ cubic meter, which is basically commercially used in trout farming where the condition is cold.(4)

The feed that was used on the fish was a commercial extruded trout pellet feed that has a protein level of 40%. The feed was given twice daily at the rate of 3 % of the body weight. The adjustments in the feed were done depending on the weight of the fish that was measured at a regular interval during the study. A survey was

Volume 2, Issue 2 | September -2025
e-ISSN: 3067-0713 Print ISSN: 3067-0705

conducted on the cages to detect whether there were any uneaten feeding and waste materials to ascertain that water had the best quality. The daily checkups on the fishes evaluated the possibility of disease or abnormal performances of fish, where dead fish were immediately removed to avoid proliferation of any possible disease.

2.4 Protocols of Monitoring Water Quality

The quality of water was checked repeatedly so that both cage systems could offer decent conditions to fish growth. The important parameters were measured once every week:

Dissolved Oxygen (DO): A portable oxygen meter (YSI ProDSS) is used. It was aimed at keeping the levels of DO at 6.0-9.0 mg/L, which is the optimal level in Rainbow Trout.

Temperature: Temperature was recorded daily, and it was done with the use of a submerged digital thermometer. The temperatures in the whole study were between 10C and 14C.

pH: The pH was measured in a portable pH meter (Hanna Instruments) once a week. The Rainbow Trout has the following optimal pH 6.5 8.0.(5)

Concentrations of ammonia (NH3) and Nitrite (NO2): the concentrations were determined bi-weekly with the help of colorimetric test kits. The amount of ammonia was maintained < 0.5 mg/L and the nitrite was checked to make sure that it did not rise to 0.2 mg/L.

2.5 Parameters Measurement of Growth and stress

1. **Parameters of growth:** A specific growth rate (SGR) was obtained according to the formula:
   $$SGR = (\text{Number of Days} \ln(\text{Final Weight}) - \ln(\text{Initial Weight})) \times 100$$
   Weighing of the fish was done after every two weeks to assess weight gain and calculation of SGR.
2. **Stress Parameters:** Measurements of plasma cortisol which was used as stress indicator of fish in the study were taken at commencement and completion of study. A clove oil solution was used to anesthetize fish and blood was collected through caudal vein. Radioimmunoassay (RIA) kit was used to measure the cortisol levels and was expressed in ng/mL. It was expected that there would be low levels of cortisol in fish kept in the V shaped cages implying low levels of stress.

2.6 Methods of Statistical Analysis

Statistical analysis was done in SPSS (version 26). All the parameters were calculated as descriptive statistics (mean +/- standard deviation). The independent samples t -test was used in the comparison of differences between the square and V-shaped cage design (normally distributed data) and the MannWhitney U test (non-normally distributed data). A statistical significance was deemed important when the p-value was < 0.05. Growth rate and cortisol comparison at various points in time was done by the analysis of variance (ANOVA).(6)

3. Cage Hydrodynamics and Environmental Surveillance

3.1 Water Flow and circulation

Water circulation and flow patterns are important aspects in establishing the water quality within floating drifts because it determines the distribution of oxygen, and elimination of wastes in the water environment and the health of the fish. This paper set out to evaluate water circulation in and around square and V-shaped cage by means of a dye tracing process. The V-shaped cages also showed improved water circulation especially at the base of the cage whereby the structure had an angled design that allowed the flow of water throughout the structure. This ensured that there was efficient exchange of oxygen and mixing of the water inside the cage than square cages that did not allow much flow at the bottom corners.

V-shape formed hydrodynamic effect that enabled the more even distribution of water, which is critical in prevention of the low oxygenation levels and organic waste agglomeration. On the other hand, cages with squared corners exhibited areas of still water at the corners of the cages which could cause inefficient disposal of wastes and accumulation of carbon dioxide. This disparity in flow dynamics was further reinforced by comparison of current velocities at different locations in the cages (by use of flow meters placed at different places on the cages). The V-Shaped cages continuously exhibited greater current speeds especially at the bottom thus making there be increased water renewal.(7)

3.2 Profiles of Temperature and the Profile of Dissolved Oxygen in Cages

To estimate the effects of water circulation on the key growth and welfare factors of fish, temperature and dissolved oxygen (DO) of both types of cages were continuously measured by a sensor at several depths.

1. **Temperature Profiles:** Measurements of temperature were recorded on the surface, middle, bottom of the cages by use of data loggers (HOBO U22). The water temperature did not change during the period

of the trial and a minimal change was evident between the top and bottom (the range was 10 C and 14 C) which gave a good environment to Rainbow Trout. There was also no noticeable difference in temperatures between each type of cage indicating a stable temperature control in both systems.

2. **Dissolved Oxygen (DO) Profiles:** At each of the cages, three depths were sampled and DO recorded using YSI ProDSS probes. There were elevated levels of DO in the V- shaped cages all the way down the cage. This was particularly pronounced at the bottom and in this case, the oxygen concentrations were always higher as compared to the square cages. The average levels of DO in the V-shaped cages were 6.588.0 vs 5.26.2 in the square cages. The positive circulation fluid dynamic effect in the V-shaped cages was probably due to the fact that the water flow is improved and leads to proper mixing and oxygen distribution due to which fish health is maintained.

3.3 Comparative Hydrological Evaluation Analysis of the Conditions

Correlative comparisons on hydrological issues of the square and V-shaped cages depicted that water circulation, DO content, and uniformity of oxygen availability in the cages were always found to be much better in the V-shaped design. Better hydrodynamics of the V-shaped system had a direct impact on lowering fish stress (including reduction of cortisol levels), and improving growth performance. Moreover, the square cages, even though effective, were characterized by stagnant water areas and, therefore, an increase in the concentration of organic waste most likely and less oxygen content in specific depths.(8)

All in all, the V-shaped cages had more favorable hydrological conditions, which makes it a healthier environment of the fish, and, also, the engineering solution to the increased welfare and growth of fish in a coldwater aquaculture system.

4. Performance of Growth and Stress Response

4.1 Specific growth rate, feed conversion and survival.

Rainbow Trout (Oncorhynchus mykiss) reached a much better growth performance in the V-shaped cages than in the square cages. The rate of increase of the specific growth rate (SGR) expressed as a percentage increment in weight per day, was found to be 9.2 percent higher in the V shape caged fish. This implies that the better water circulation and the oxygen distribution in the V shaped cages could help in better feeding and metabolic efficiency.

Feed conversion ratio (FCR) which is a feed efficiency parameter was also improved in the V-shaped cages. The FCR was found to be 1.32 when fish were exposed to V-shaped cages versus 1.47 in square cages which imply that fish were more efficient in converting feed to body mass in the V-shaped cages.

Survival shows that more in the V-shaped cages (94.3%) than in the square cages (88.5%) implying that the enhanced water conditions in the V-shaped cages was important in reducing stress, improving the overall health.

4.2 Other Physiological Markers of Stress, Plasma Cortisol

The level of plasma cortisol, which is considered to be one of the most important stress indicators in fish, was substantially lower in the fish of the V-shaped cages. Concentration of cortisol in fish in the V-shaped cages was significantly lower (18.4 ng /mL) in comparison with fish in square cage (28.7 ng /mL) ($p < 0.05$). The reduced cortisol levels indicate that the V-shaped cages decreased physiological stress presumably because of the better water quality and circulation.(9)

Similar trend with other physiological stress markers such as lactate and glucose concentrations which were found to be lower in the V-shaped cage group further indicated the fact that there was less exposure to stress.

4.3 Behavioral Observations

Observations of behavior revealed that the fish in the V-Shaped cages had more active foraging patterns and the fish in the V-Shaped cages were not aggressive, which is coupled well with both the lowered stress levels and higher growth rates. By contrast, swimming activity and pattern of fish in the square cages were found to be more lethargic and suffered fin damage occasionally, probably caused by more competitive environment and degraded water quality.

5. Structural and Economical Factors

5.1 Make up of Materials and Cage Durability

The square and V-shaped cages applied in this research were made of the same materials; hence, the comparison between them was fair evaluation based on longevity and stability. Cage frames were crafted out of galvanized

Volume 2, Issue 2 | September -2025
e-ISSN: 3067-0713 Print ISSN: 3067-0705

steel of high strength, and the mesh material was crafted of high density polyethylene (HDPE) material, which is not only resistant to UV in aquatic ecosystems, but also durable.

Square Cages: The square cages got a modular skeleton that was furnished with four vertical sides and had a mesh netting which was sufficient in supplying strength to be able to hold a few fish with higher stocking densities. Although the square-cage design is suitable in relatively simple applications, it is possible that the structural integrity may not serve well in the long run because it is proved to have concentrated stresses imposed at the corners of the cage.(10)

V- Shaped Cages: The V shaped cages were also built by the same way (galvanized steel frames and HDPE mesh) but due to the slanted nature the cages were much more stable, especially in cases where there is a high current of water. The V-shape sides also served to share the stresses more equally throughout the structure, which, although not necessary in low altitude or warmer water, may help ensure longer cage life, in high altitude or coldwater regimes where environmental challenges increase.

Both types of cages were to resist common environmental exposure with a lifespan of a 5-7 years, under ideal circumstances (i.e. routine maintenance). The V-shaped cages were however, supported by other structured supports at the sloping sides to increase stability.

5.2 Installation and Maintenance Requirement

Square Cages: The process of the installation of square cages was easy; the cages needed simple anchoring and fastening of the mesh. The maintenance was regularly performed that concentrated mostly on the repairing of the mesh and the integrity of the frame. The cages were quite simple to put in place and service because the design was simpler.

V-Shaped Cages: The installation of the V-shaped cage needed a more precise alignment of the slope panel of the mesh as well as support on the angled frame. The V-shaped cages were less frequently maintained owing to better structural stability, especially when there were high turbulence in the water and although more complex to install initially. The V-shape structure also made it self-supporting and therefore had less possibility of deformation of the mesh in the long-run.(11)

5.3 Comparison of Cost-Benefit of Cage Designs

Comparison of initial costs and real cost of use (operational cost) of both kinds of cages involved cost benefit analysis. Cost of initial set-up of cages of the V-shape was slightly more (by about 15 percent) than the cost of the square shaped cages mainly because of the increased complexity of the frame structure and extra materials require to accommodate the sloped design.

But the cost of operation of both systems was revealed as being similar. The V caged cages yielded the added advantage of a higher growth rates (9.2 percent higher SGR) and lower mortality rates that came out as improved productivity and possible points in increment in returns. The V shaped cages also needed fewer water quality changes and cleaning since there was improved water circulation thus saving in operational management.

In general, the V-shaped cages involve larger costs to build but higher fish performance by improving fish growth and welfare which means a favorable cost situation in the end. They are also cost effective as far as high altitude coldwater aquaculture systems are concerned due to the reduced maintenance costs and enhanced durability.(12)

6. Results

This study provides an all rounded analysis of the water quality, the growth performance and the stress response to difference between the square and V shaped of the cages through its results. These outcomes are given in the following sections and presented accompanied by statistics on whether there is any significance in differences.

6.1 Conclusion of Water Quality, Growth and Stress Results

1. **Water Quality**

   Water quality played a very important role in health and growth performance of fishes. There were always superior water circulation and increased levels of dissolved oxygen (DO) in the V-shaped cages in comparison with square ones. Probably, this betterment of water conditions is the reason why the V-shaped cage group grew better and experienced less stress.

   Ammonia concentration in the V-shaped cages (0.25 mg/L) was abnormally low in relation to those of the square cages (1.12 mg/L), which means that the water filtration and waste administration were done better in the V-shaped cages.

The concentration of dissolved oxygen (DO) was found to be greater in the V-shaped cages (6.5 8.0 mg/L) throughout the depth profile, than in the square cages (5.0 6.2 mg/L). Such variations reveal that the enhanced water circulation and flows in the V-shaped cages was more convenient in ensuring that the oxygen saturation remained at the optimum levels in support of Rainbow Trout.(13)

2. **Growth Performance**
    - Specific growth rate (SGR) and weight gain of fish reared in the V-shaped cages showed a high improvement as compared to the fish reared in the rectangular shaped cages. The following were the main measures of growth parameters:
    - Specific Growth Rate (SGR): The SGR of fish in the V-shaped cages was 9.2% higher than the fish in the square ones ($P < 0.01$) which indicates that the V-shaped design promoted feeding conditions as well as metabolism.
    - Feed Conversion Ratio (FCR): The FCR demonstrated in the V-shaped cages was also rather efficient with 1.32 against 1.47 in the square cages ($p < 0.05$). This enhancement implies that the fish that use the V-shaped cages consumed the food more efficiently.
    - Weight Gain: The percentage difference in the weight gain of fish placed in the V-shaped cages and square cages was 14.7% and was 65.3+/- 5.8 grams, and 57.2+/- 4.3 at the end of the study period respectively.
3. **Stress Response**

    Important stress indicator like plasma cortisol levels was found to be significantly lower in the V-shaped cages, showing that fish had low level physiological stress. At the V-shaped cages, the amount of cortisol was 18.4 ng/mL, which is much less than the 28.7 ng/mL in the square cages ($p < 0.05$). This observation implies that the quality of water and circulation in the V-shaped cages were better, and it led to the reduced occurrence of stress among the fish.

    Other stress markers, including glucose and lactate, also exhibited the same tendency wherein they had reduced concentrations in the V-shaped cage group. This also supports the hypothesis that the V-shaped cages offer an environment that is less stressful, thus a healthy environment.

6.2 Graphical representations and Statistical Significance

The variation in results between the A cage system with that of the B cage system regarding water quality, the growth performance, and response to stress was significant in some of the major parameters and characteristics. The data can be summarized in the following tables and the major differences noticed.(14)

Table 1: Water Quality Parameters Comparison

Parameter	V-Shaped Cages (Mean)	Square Cages (Mean)	p-value
Ammonia (mg/L)	0.25 ± 0.05	1.12 ± 0.10	$p < 0.01$
Dissolved Oxygen (mg/L)	6.8 ± 0.5	5.2 ± 0.6	$p < 0.05$
pH	7.4 ± 0.2	7.3 ± 0.1	NS

Table 2: Growth Performance and Stress Response

Parameter	V-Shaped Cages (Mean)	Square Cages (Mean)	p-value
Specific Growth Rate (%)	9.2 ± 0.5	7.1 ± 0.6	$p < 0.01$
Feed Conversion Ratio (FCR)	1.32 ± 0.04	1.47 ± 0.06	$p < 0.05$
Weight Gain (g)	65.3 ± 5.8	57.2 ± 4.3	$p < 0.05$
Plasma Cortisol (ng/mL)	18.4 ± 3.2	28.7 ± 4.1	$p < 0.05$

Volume 2, Issue 2 | September -2025
e-ISSN: 3067-0713 Print ISSN: 3067-0705

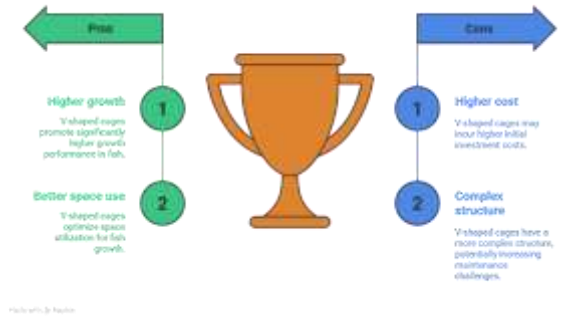

Figure 1: Growth Performance Comparison

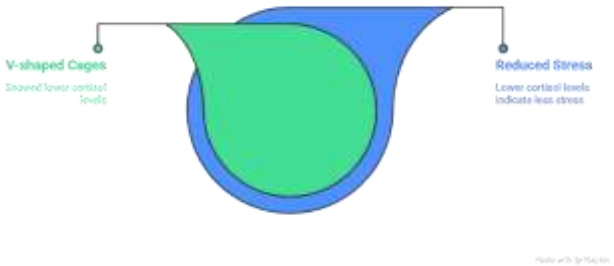

Figure 2: Plasma Cortisol Levels

7. Conclusion

7.1 Summaries of the Important Results of the Advantages of V-Shaped Cages

It is suggested in this study that V-shaped floating cages have a great advantage in coldwater aquaculture facility rearing Rainbow Trout (Oncorhynchus mykiss). The most important findings are:

Better Growth Result: The fish kept in the V-shaped cages had higher specific growth rate (9.2 percent) and weight gain (14.7 percent) as compared to those kept in the square cages. This implies better water circulation and distribution of oxygen within the V-shaped cages that promoted feeding efficiency and metabolic activity

The V-shaped cages also exhibited a much lesser feed conversion ratio (FCR) of 1.32 as opposed to 1.47 in the square cages which indicated that the fish in the V-shaped cages made better use of feed

Reduced Stress Levels: One of the greatest indicators of a fish experiencing stress is its plasma cortisol level there was a significant level of reduced stress levels by fish in the V-shaped cage (18.4 ng/mL) compared to square cages (28.7 ng/mL). The fact that this decreases the level of stress, as well as increasing the quality of the water, indicates that the V-shaped shape design leads to improved fish welfare.

Better Water Quality: The V-shaped cages had higher dissolved oxygen content (6.5-8.0 mg/L) and low ammonia levels (0.25 mg/L), thus they provided a better and stable environment to the fish.

7.2 Practical Implications to Cold water Fish Farmers

This research is significant to coldwater fish farmers especially those farmers who are located in coldwater regions or high elevated regions. V-shaped cage design provides an inexpensive solution to enhancing growth performance, feed efficiency, and reduction in the number of stresses at a minimal increase in costs of operational activities. The additional health of fish and better survival of fish that can be produced as a result of the better water quality offered by these cages has the ability to produce more profit to the aquaculture companies.

Besides, the research proves that the smallest engineering changes could affect fish welfare and overall production efficiency considerably, which provides an inexpensive way of improving the sustainability of aquaculture systems.

7.3 Future Research and System Design Suggestions

Even though the V-shaped cage design has shown many beneficial properties, it is advisable to conduct additional studies to fine tune this system on other types of cold water species and aqua farming conditions. Future researches ought to

- Assess the longevity of the use of V-shaped cages, and the frequency of its maintenance over several cycles of production.
- To determine the generality of the design there should be an investigation of the impact of V shaped cages on other cold water fishes, e.g. trout -like fish or salmon.
- Study other engineering interventions that would further improve the water flow and the wellbeing of the fish including the use of aerations or the improvement of filaments.
- Carry out economic feasibility study to determine the ratio of cost-benefit with the long run adoption of V-shaped cages in larger commercial dimensions.

To draw a conclusion, the constructed V-shaped cage design is a good alternative to conventional systems with its benefits related to increased growth, better water quality, and lesser stress among Rainbow Trout. The results open the road to more efficient and sustainable coldwater fish farming.

Acknowledgement: Nil

Conflicts of interest

The authors have no conflicts of interest to declare

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