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Feasibility Report – Ento-Feed

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1. Executive Summary

The report project detailed analyses of the issues and challenges of developing fish feed from insect larvae, particularly Black Soldier Fly (BSF) Larvae, in the context of the areas in which the Blue Gold (BG) programme operates.

The contracting parties have identified key constraints on the growth of aquaculture in the BG target areas from qualitative data collected directly from the fish farmers in the BG target areas. One of the key constraints is: access to high quality and competitively priced fish feed. And the contracting parties have provided a detailed and through approach about the way this challenge can be overcome.

The solution proposed by this report is the use of BSF larvae as a complete or partial substitute for the fish feed (both commercial and non-commercial) that is currently used by the fish farmers to cultivate their fish stock. The main advantage of this approach is the fact that the farmers can have complete control over the quality of feed that they provide to their fish, at a much lower cost.

By making the farmers more independent, it is submitted that this technology has the potential to revolutionise the aquaculture industry in this county. However, given the novel nature of the technology, many practical concerns have to be addressed first before the technology can be widely implemented.

The report provides thorough analyses about the ways these issues can be addressed and proposes two practical business strategies (decentralised model and centralised model) for commercialising the technology. It is submitted that a decentralised business model for developing the technology would be very beneficial for the fish farmers in the BG target areas because it would enable the farmers to actively participate in a new industry and directly benefit from this technology.

Finally, the report provides a detailed plan for implanting the pilot which will form the basis for commercialising the technology in the BG target areas in the future.

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2. Introduction

This report is the culmination of the research and analysis that has been done in relation to the development of Black Solder Fly (BSF) larvae as partial or complete substitute for commercially based fish feed in the regions of Bangladesh where Blue Gold (BG) operates.

The objective of the report is to provide a detailed analysis of the myriad challenges faced by the fish farmers in the BG target areas and then provide a solution for resolving the constraints that these aquaculturists (fish farmers) face in relation to accessing high quality fish feed at competitive prices. It is submitted that rearing BSF so that its larvae can be used by the farmers as partial or complete substitute for commercially available fish feed, could provide a viable solution to the challenge associated with fish feed.

Two approaches for developing the use of BSF larvae as fish feed: *Decentralised Model* and *Centralised Model*, are analysed in detail in this report. The paper, then, sets out the structure for developing the decentralised model in the areas where BG operate because it is considered to be the most effective method for commercialising the project at present, given the socio-economic, climate conditions and associated risks.

After that the paper provides a detailed financial analysis of the financial aspects of the decentralised model. The financial aspects of the centralised model are not considered because that approach would not be considered appropriate at this stage of development.

Then the paper looks at the socio-legal concerns that could arise in relation to the use of insect larvae as an alternative fish feed and then provides a through critical success factors analysis. This analysis sets out the issues that are crucial for the success of using insect larvae as alternative fish feed.

Finally, the paper provides a plan and cost estimation for the implementation of the pilot project in the BG target areas. The primary focus of the pilot project is the collection of data which would form the basis for commercialising this concept.

3. Constraints on the Development of Aquaculture in BG Target Areas

Aquaculture industry in Bangladesh has been growing very quickly. From 1984 to 2014 fish annual production from aquaculture increased from 124,000 tons to 1.96 million tons, an increase of 1580 per cent. This industry has helped many small scale farmers to increase their income and move out of poverty.

Despite the massive growth of aquaculture in the BG target areas, qualitative research, which included interviewing the aquaculturists in the target area, conducted by Aspire with the help of Insectsforall has provided some valuable insights about the organisation and the operation of aquaculture in the target areas. The key constraints for further development of the aquaculture industry in Bangladesh can be divided into the following three categories: lack of formalisation, limited access to resources and insufficient quality control of the essential inputs.

3.1 Lack of Formalisation

Discussion with the fish farmers and people who were involved in fish farming reveals that the fish production in the BG target area is generally organised in an informal manner. The primary purpose of fish farming for most people engage is to supplement their income. Although some people rely on fish farming as their primary source of income, it is quiet evident that most farmers do not understand the significance of proper documentation of their activities. They perceive documentation as a hindrance to their economic activity; consequently they have not been keeping detained records of their activities.

For example, the farmers did not have precise ideas about the their production targets or the amount of input they needed to reach their respective goals. Most of them had a general idea about the inputs they needed for their production; however, they did could not articulate their expected return on their capital investment or the amount of feed they needed per hectare for the production of their chosen fish. Additionally, they did not keep accurate and regular records of the quality of the water, such as oxygen level, nutrient level, pH level, etc., which are essential to optimise the production of fish.

Finally, the farmers do not have precise information about the risks associated with fish production. Their inability to assess the risks of engaging in a certain activity leaves them exposed to unnecessary risks which mean that they are unable to take develop sufficient contingency plans that would enable them to handle unexpected events in a manner that does not jeopardise their economic activity.

The lack of formalisation of the production process means the farmers are not optimising the resources that are at their disposal. Despite the informal approach to fish farming, the industry has developed tremendously in the last two decades.

The success of these farmers is a testament to their ability to persevere and their ingenuity because they have continued to prosper and grow despite the lack of formalisation. The success of the fish farmers can also be attributed to the help and support of the Blue Gold and the Government of Bangladesh programme which has provided these fish farmers with valuable skills relating to live stock and water quality management.

3.2 Limited Access to Resources

In addition to the lack of formalisation in relation to fish production, farmers in the BG target area have also raised concerns about the limited resources at their disposal. Many farmers have raised concerns about financing because banks and other financial institutions have been reluctant to give them a line of credit which would enable them to finance their operational cost.

Financing these activities is a key issue because fish production takes place in stages. During the growth phase of fish production, fish farmers have to invest a lot of money to feed the fish and ensure that their fish stock does not succumb to diseases. Fish farmers have expressed that the lack of financing means that many farmers had limited options in relation to the choice of feed because they were only able to acquire feed which were available on credit. Consequently, the primary criteria for feed acquisition was not the nutritional quality of the feed but the availability of credit for the purchase of the feed.

Furthermore, there is a marked lack of skilled scientific investigators who can assess the health of the fish and make necessary recommendation to reduce the loss of fish stock due to health related issues. The farmers had limited idea about the risks of intensive cultivation of fish. They did not have any idea of the potential diseases that could arise in their fish stock, or have access to an expert who could inform and guide about the proliferation of location specific diseases.

Some of the farmers in the Patuakhali region were very concerned about a mysterious disease which has wiped large portion of their shrimp. Further questions revealed limited information about the causes for the loss of their shrimp stock. Some of them ventured some guesses, but they were essentially anecdotes which were not substantiated by any concrete evidence. Despite the lack of proper investigation, the farmers have tried to deal with this issue in their own way.

The fish farmers suggested that adding certain chemicals have improved the survival rate of their fish stock. However, they were unable to articulate what chemicals they have used and how did that improve the health of their fish stock. Their primary focus seems to have been to ensure that the ponds and water bodies are thoroughly disinfected after each yearly cycle with lime, and additional chemicals. Their approach seems to have been prevention is better than cure.

Although this approach is commendable, the farmers seem to be mindful of the threat of diseases and they seem quite helpless when inquiries were made about the treatments that were available to them to save their fish stock. Furthermore, it seems that the farmers are not well versed about concepts such as stocking density of fish stock, the ideal pH number, dissolved oxygen content in the water and other factors that can have a major impact on the growth and the health of their fish stock.

3.3. Lack of Quality Control

The lack of adequate quality control is a major cause of concern from a business perceptive because it means that many farmers waste valuable resources while cultivating their fish stock. Additionally, the lack of proper supply chain management means that the farmers are unable to differentiate their product and add value to their production.

During the interview, it became evident that there was no way for the fish farmers to authenticate the quality of the fish feed that they were purchasing. Closer examinations on this point revealed that the farmers were completely dependent on the judgment of the local feed suppliers when making their selection of feed. The farmers did not have much understanding of the nutritional requirements of their fish stock and they acquiesced that the only way that they could determine the validity of the claims made by a distributor in relation to a specific feed was by using the feed. This meant that the farmers would have to bear the risk of loss, if their fish did not grow properly.

From an economic perspective this raises a issue, namely the alignment of incentives. Given the way the aquaculture industry is set up in Bangladesh, the incentives of the distributors and the incentives of the fish farmers are at odds. This is because the distributors are only interested in promoting products by manufacturers who give them the biggest profit margins; whereas, the farmers are primarily interested in a nutritious feed at competitive prices. Since the farmers are unable to validate the quality of the feed they purchase from the distributors, the distributors have the incentive to promote sub-par products, even though it would lead to lower yields for the fish farmers, if that allows them to make higher profits.

Additionally, given the financial constraints of the farmers, the distributors are able to push sub-par fish feed to the unsuspecting fish farmers because farmers would have face the choice of either feeding poor quality feed to their fish or risk significant loss due to malnutrition of their fish stock.

Additionally, it seemed that the farmers were not aware of proper water management and stocking density. As the density of fish is increased, the water has to be actively managed to ensure optimal growing conditions for the fish. Most of the farmers in Bangladesh do not engage in intensive fish farming because that involves tools to monitor the quality of the water, such as dissolved oxygen, pH level, nitrite levels, etc. The fish farmers are aware of the complexity of the ecosystem in which fish are cultivated; however, they lack a thorough understanding of the issues and the ways of mitigating them.

Most of the fish farming is quite passive, in the sense that farmers conduct limited monitoring and modification to the water quality. The main concern of the fish farmers seem to be providing fish feed.

Additionally, many farmers provide home made fish feed to their fish stock. Although this is quite a commendable practice, their dearth of knowledge in relation to the nutritional requirements for their fish stock means the fail to maximise their production.

3.4 Conclusions

Despite the myriad challenges, the farmers have done remarkably well with the support of BG team and the Government of Bangladesh. Through trial and error they have improved their cultivation process, which provides them with a unique perspective about the needs of their fish stock. However, the inefficiencies in the industry are catching up and have eroded the profits of fish farmers and have increased their exposure to new risk factors. Given that it is not possible to resolve all the constraints in one attempt, Aspire and Insectsforall have decided to focus on ONE aspect of fish cultivation, namely *access to high quality fish feed at very competitive prices*, which would have a significant positive impact on the growth of aquaculture in the BG target areas.

4. Insects (Black Soldier Fly) as the Solutions

The project will consider the feasibility of rearing Hermetia illucens (black soldier fly or BSF) using their larvae to primarily supplement fish feed for the BG farmers in the BG target area, although the larvae could also be used as alternative animal feed. Considerations will also be given for the utilisation of the larvae castings as organic fertiliser.

4.1 Black Soldier Fly (BSF)

Rearing Hermetia illucens has been proposed since the 1990s as an efficient way to dispose of organic wastes, by converting them into a protein-rich and fat-rich biomass suitable for various purposes, including animal feeding for all livestock species, biodiesel and chitin production (van Huis et al., 2013; Diener et al., 2011). The black soldier fly is an extremely resilient species capable of dealing with demanding environmental conditions, such as drought, feed shortage or oxygen deficiency (Diener et al., 2011). One major advantage of BSF over other insect species used for biomass production is that the adult does not feed and, therefore, does not require particular care. It is also not a potential carrier of disease. The larvae are sold for pets and fish bait, and they can be easily dried for longer storage (Leclercq, 1997; Veldkamp et al., 2012). Biodegradation by BSF requires a warm environment, which makes it suitable for the climate of Bangladesh. Also, the duration of the life cycle ranges between several weeks to several months, depending on ambient temperature, and the quality and quantity of the diet (Veldkamp et al., 2012). In aquaculture, using feeds based on BSF larvae open additional marketing opportunities for farmers as some customers are opposed to the use of fishmeal in aquaculture feeds (Tiu, 2012).

BSF can be used commercially to solve a number of environmental problems associated with manure and other organic wastes. Adult flies are not attracted to human habitats or foods and not considered a nuisance (van Huis et al., 2013).

Black soldier fly larvae are a high-value feed source, rich in protein and fat. They contain about 40-44% dry mass (DM) protein. The amount of fat is extremely variable and depends on the type of diet and on its fat content: reported values are 15-25% DM (larvae fed on poultry manure, Arango Gutierrez et al., 2004), 28% DM (swine manure, Newton et al., 2005), 35% DM (cattle manure, Newton et al., 1977), and 42-49% DM (oil-rich food waste, Barry, 2004). They tend to contain less protein and more lipids than housefly maggots (Musca domestica). Ash content is relatively high but variable, from 11 to 28% DM. The larvae are rich in calcium (5-8% DM) and phosphorus (0.6-1.5% DM) (Newton et al., 1977; St-Hilaire et al., 2007b; Arango Gutierrez et al., 2004; Yu et al., 2009). The amino acid profile is particularly rich in lysine (6-8% of the protein). The dry matter content of fresh larvae is quite high, in the 35-45% range, which makes them easier and less costly to dehydrate than other fresh by-products (Newton et al., 2008).

The fatty acid composition of the larvae depends on the fatty acid composition of the diet. The lipids of larvae fed cow manure contained 21% of lauric acid, 16% of palmitic acid, 32% of oleic acid and 0.2% of omega-3 fatty acids while those proportions were 43%, 11%, 12% and 3%, respectively, for larvae fed 50% fish offal and 50% cow manure. Total lipid content also increased from 21% to 30% DM. Feeding black soldier fly larvae with a diet made of wastes containing desirable omega-3 fatty acids is, therefore, a way to enrich the final biomass (St-Hilaire et al., 2007b).

4.2 Nutritional Profile of larvae (dehydrated)

Analysis of the larvae demonstrates that they have a very high crude protein content (approximately 42%, see fig 1.1 below). The larvae are rich in all the essential amino acids arginine (required for the young, but not for adults), histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine (see fig 1.3 below). However, the relative deficiency of methionine, cystine and threonine means that in some cases it may be necessary to supplement feed based on BSF larvae with other feed. The deficiency has not been an issue in trials conducted on fish; however, they were an issue in trials conducted on pigs. The larvae are also rich in calcium and phosphorus which are very helpful for fish growth.

The nutrition (including the amino acids and minerals) that can be obtained from BSF larvae would make it an ideal (complete or partial) substitute for fish feed that is currently available in the market because the larvae can offer a very balanced diet to the fish.

The figures below provide a global analysis of the key constituents of the larvae. (Keys: Avg: average; SD: standard deviation; Min: minimum; Max: maximum; N: number of samples)

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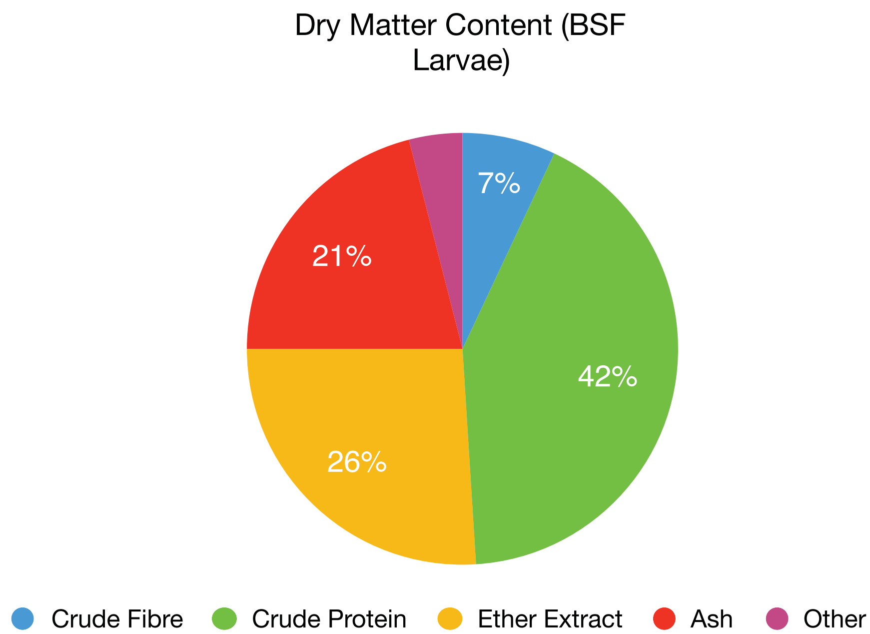

Fig 1.1 Dry Matter Content (anhydrous)

Main Analysis	Unit	Avg	SD	Min	Max	N
Dry Matter	% as fed	91.3	1.1	90	92.5	5
Crude Protein	%. DM	42.1	1	41.1	43.6	5
Crude Fibre	%. DM	7				1
Ether Extract	%. DM	26	8.3	15	34.8	5
Ash	%. DM	20.6	6.0	14.6	28.4	5

Fig 1.2 Dry Matter Content of BSF Larvae (anhydrous)

4.3 Research Trials

This section provides details of the various trials that have been conducted by researchers in relation to the use of BSF larvae as alternative feed for fish, crustaceans and other live stock; and the use of larvae castings as organic fertiliser. Emphasis will be given to the research trial that has been conducted in Bangladesh, because that is directly relevant to the current project.

4.3.1 Research Trials in Agricultural University Bangladesh

Researchers at the Agricultural University of Bangladesh (Rana, et al 2015) have conducted successful trial for the production of BSF larvae in Bangladesh. The trial lasted for three months. The larvae were used as a substitute of fishmeal in fish feed formulation. BSF larvae were grown on different organic wastes namely rotten wheat, vegetables and mustard oil cake. The average production of BSF larvae from rotten wheat, vegetables and mustard oil cake were 185.98±57.41, 133.69±24.76 and 48.38±14.04 g/kg waste, respectively. This suggests that 18.6, 13.37 and 4.84 % of the rotten wheat, vegetables and mustard oil cake, respectively were converted into larval biomass.

The results of their trial show that complete substitution of fish feed with BSF larvae produced similar growth in tilapia when compared to tilapia fed on fish feed. However, optimal result in relation to the growth of fish was achieved when 50% of the fish feed was substitute with BSF larvae.

The study provides directly relevant information in relation to the use of BSF larvae as a partial or complete substitution of fish feed for aquaculture in Bangladesh.

4.3.2 Fish

Several experiments have shown that pre-pupae BSF could be a partial or full substitute for fish meal in fish diets in different jurisdictions. However, additional trials as well as economic analyses are still necessary as reduced performance has been observed in some cases. The type of substrate (organic waste) on which the larvae are reared and the processing method affect the utilisation of the larvae by fish.

Channel catfish (Ictalurus punctatus)

Chopped BSF larvae grown on hen manure fed to channel catfish alone or in combination with commercial diets resulted in a similar performance (body weight and total length) as the control diets. Aroma and textures of channel catfish fed larvae were acceptable to the consumer (Bondari et al., 1981). A later study was less favourable: replacement of 10% fish meal with 10% dried soldier fly larvae resulted in slower growth over a 15-week period for sub-adult channel catfish grown in cages. However, the substitution did not reduce growth significantly when channel catfish were grown in culture tanks at a slower growth rate. Feeding 100% larvae did not provide sufficient dry matter or protein intake for channel catfish grown in tanks to allow a sufficient growth. Chopping of the larvae improved weight gain and efficiency of utilisation (Bondari et al., 1987). A comparison between menhaden fish meal and black soldier fly pre-pupae meal showed that the latter could be advantageous as a replacement for fish meal, but that an inclusion rate higher than 7.5% was unnecessary (Newton et al., 2005).

Blue tilapia (Oreochromis aureus)

Chopped black soldier fly larvae grown on hen manure fed to blue tilapia alone or in combination with commercial diets resulted in a similar performance (body weight and total length) as the control diets. Aroma and texture of tilapia fed larvae were acceptable to the consumer (Bondari et al., 1981). In a later experiment, feeding 100% dry larvae did not provide sufficient dry matter or protein intake for tilapia grown in tanks to allow a sufficient growth. Chopping of the larvae improved weight gain and efficiency of utilisation of the larvae (Bondari et al., 1987).

Rainbow trout (Oncorhynchus mykiss)

Dried ground BSF pre-pupae reared on dairy cattle manure enriched with 25 to 50% trout offal replaced up to 50% of fish meal in trout diets for 8 weeks without significantly affecting fish growth or the sensory quality of trout fillets, though a slight (but non-significant) reduction in growth was observed (Sealey et al., 2011). In a nine-week study, replacing 25% of the fish meal component of rainbow trout diets with BSF pre-pupae meal, reared on pig manure, did not affect weight gain and feed conversion ratio (St-Hilaire et al., 2007a).

Turbot (Psetta maxima)

Juvenile turbot accepted diets containing 33% defatted black soldier fly larvae meal without significant effects on feed intake and feed conversion. However, specific growth was reduced at any inclusion rate. Higher rates reduced intake and nutrient availability, with a further reduction in growth rate, possibly because of the presence of chitin (Kroeckel et al., 2012).

4.3.3 Crustaceans

Giant river prawn (Macrobrachium rosenbergii)

In Ohio, BSF larvae meal, reared on dried distillers' grains, fed to commercially reared prawns, resulted in a similar performance as regular prawn feed, with better economic returns. The prawns fed larvae meal were of a lighter colour (Tiu, 2012).

4.3.4 Poultry

As a component of a complete diet, BSF larvae meal has been found to support good growth in chicks. Chicks fed a diet containing dried BSF larvae as the protein supplement gained weight at a rate of 96% that of chicks fed soybean meal plus fat (non-significant), but they only consumed 93% as much feed (significant) (Hale, 1973).

4.3.5 Pigs

BSF larvae meal was found to be a suitable ingredient in growing pig diets, being especially valuable for its amino acid, lipid and calcium contents. However, its large ash content and its relative deficiency in methionine, cystine and threonine require that it is included in a balanced diet. It was as palatable to pigs as a soybean meal based diet (Newton et al., 1977).

Dried BSF pre-pupae meal was fed to early weaned pigs as a replacement (0, 50, or 100%) for dried plasma (5% during a first phase, 2.5% during a second phase, and 0% during a third phase), with or without amino acid supplementation. Without amino acid supplementation, the 50% diet gave slightly better performance during phase 1 (4% extra gain, 9% increase in feed efficiency). However, the 100% diets did not perform as well as the control and overall performance was reduced by 3 to 13%. Additional refinement (cuticle removal and rendering) may be necessary to make pre-pupae BSF suitable for early weaned pigs (Newton et al., 2005).

4.3.6 Organic fertiliser

Dense populations of larvae can convert large volumes of organic waste into valuable biomass (van Huis et al., 2013). For instance, larvae can reduce the accumulation of manure from laying hens and pigs by 50% or more without extra facilities or added energy (Sheppard et al., 1994; Newton et al., 2005; Barry, 2004). In Costa Rica reduction values of 65-75% have been observed in field trials with household waste (Diener et al., 2011). In confined bovine facilities, the larvae were found to reduce available phosphorous by 61-70% and nitrogen by 30-50% (Newton et al., 2008).

4.3 Relevance for BG Farmers

Research that has been conducted on the use of BSF larvae as an alternative fish feed indicates that there is an immense opportunity for the fish farmers in the BG target area because most of these farmers are involved in cultivating white water fish such as tilapia, carp and crustaceans such as salt water prawns. Although these research have not been conducted on the specific species cultivated by the fish farmers, the research provides a strong basis for carrying out further research in the target area to determine the benefits that can be conveyed to the target farmers.

Additionally, using BSF larvae can offer a great opportunity for other people in the BG target area who are involved in rearing poultry and pigs, because the feed produced from BSF larvae has been used to feed these animals in research trials, but also on commercial scale. Further exploration is needed on this issue to ensure that the technology can be optimised for the specific conditions in the BG target area.

Finally, the larvae castings produced from rearing BSF can also be used by the farmers to fertilise their agricultural produce. Since the fish farmers of the BG target area engage in simultaneous cultivation of fish and high value vegetable, the development of this technology can offer some significant positive externalities.

4.4 Conclusions

This section has demonstrated the research that has already been conducted in relation to the use of BSF larvae as fish feed and animal feed. Additionally, the larvae casting can also provide a valuable source of income for the farmers engaged in fish farming because they could either sell the worm castings of use them for their own agricultural production reducing their reliance on fertilisers from traditional sources.

Research in Bangladesh and around the world indicates that fish feed produced from BSF larvae can provide a viable alternative to commercially available feed. These findings merit further exploration to optimise the benefits of this technology given the environmental conditions of the BG target areas.

A number of organisations (such as AgriProtein in South Africa, Enviroflight in USA, Enterrafeed in Canada and J M Green in China) are already involved in commercialising the use of insect larvae based fish feed; however, the industry is still in its infancy which means that successful implantation of the technology requires further exploration. The next section will delineate the technical challenges and how they can be resolved.

5. Technical Aspects of Rearing BSF Flies

This section provides detail analysis of the life cycle of BSF flies, the optimal climate conditions for its growth, the resources that would be required to ensure cultivate BSF larvae, the nutritional profile of the BSF larvae, the expected yield of BSF larvae and the ways the larvae can be processed to optimise their use as fish feed.

5.1 Life cycle of the Black Soldier Fly

The black soldier fly (Hermetia illucens) is a black coloured fly with two wings. The size is comparable to a wasp. The black soldier fly can be found in nature in the warmer regions. They can be detected especially around decaying organic matter as animal waste or plant material. There are varied species of the black soldier fly.

The life cycle of a black soldier fly can be described in four (or five) stages: egg, larvae, (prepupae), pupae and adult.

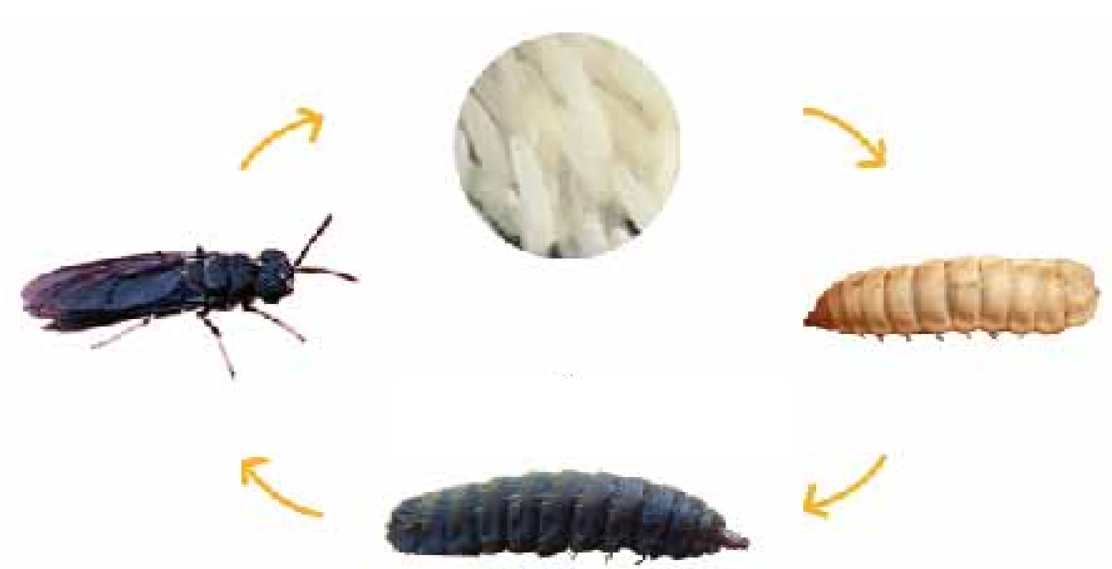

Fig. 2 Life cycle of a black soldier fly

Each stage has its own characteristics which should be considered when breeding.

5.1.1 Adults

An adult BSF can start to mate between two to four days after emerging from the pupal case. Males will wait for passing females and meet them in mid-air. Then they descend in copula and mate on the soil/substrate. Aerial questing (stimulated by light) is important. Air flow is quite an essential requirement for the BSF to copulate. Additional critical elements for the flights to mate are temperature and ambient light levels.

Males are territorial and will often defend their territory. Adults BSF doesn't eat and rely on their fats stored from the larvae stage. Therefore, they have no mouths. This means that the flies do not play any role in the propagation of diseases. The BSF species is not considered a disease vector or a nuisance to humans, but some cases of infections are known.

Presence of BSF will reduce the presence of the house fly, because BSF larvae compete with the house fly larvae during their growth phase and eradicate them. Adults BSF will die if the temperatures become too low or normally when they have depleted their fat reserves.

5.1.2 Eggs

Female BSF will deposit their eggs in a mass of 500 eggs. Fertilised females / eggs can be detected by their 'translucent windows' on the first abdominal. It gets a more yellow colour. The BSF deposit the eggs in cracks and narrow crevices near, but not in, decaying matter. The eggs are not placed directly on or in the waste.

Strategically placed pieces of cardboard or flutes can be used to collect the eggs. Dung, carrion, garbage, or other type of organic waste can be used as decaying matter to attract the female BSF to lay their eggs.

The eggs hatch into larvae in about 4-5 days at an optimal temperature of 26-30 degrees centigrade. The eggs are oval shaped and about 1 mm in length, and are pale yellow or creamy in colour.

5.1.3 Larvae

A larva can grow to about 27 mm length and 6 mm width. Larvae are whitish coloured and segmented. Usually larvae pass 6 instars which takes about 14 days. Other sources mentioned 21-28 days before they get into the pre-pupae phase. The larvae are quite robust and they can survive harsh conditions. However, under optimal conditions they thrive. During this stage, the larvae eat continuously. Fast growing larvae need smaller amounts of food, while slower growing species convert more waste.

The speed of development can be managed depending on the specific requirements. Typical daily feeding rates for larvae are range from 50-175 mg/larva/day. Given the high consumption of waste by BSF larvae, odour of the waste can be reduced relatively quickly. Larval growth can be increased by adding oxygen to the waste matter by mixing air into the matter or turning the feed on which larvae feed.

5.1.4 (pre-)Pupae

When a larva has reached the six instar (pre-pupae stage) they disperse from the feeding place to dry sheltered areas, such as ground vegetation. They have a tendency to climb out of their feeding material in search of a dry place to pupate.

They look for drier and darker places to shelter and the area should be porous and loose to allow for easy burrowing of wandering pre-pupae. Probably some material where they can burrow themselves. Max depth is 15-20 cm. Not too fine material. Wood chips, which are smaller than the pupae. This makes it easier to sieve the material and take out the pupal casing, which could be a risk for pests and/or be used as industrial source for chitin.

They can migrate considerable distances and attach themselves to a variety of surfaces and therefore be found in all places.

Exposing the larvae to light, stimulates the migration of pre-pupae. Water can be used to wet the slope to stimulate the migration. The exoskeleton (skin) darkens during pupation.

The pupation takes about two weeks. The pre-pupae are the best to harvest, which can be done easily, because they disperse from their feeding place. The pre-pupae can be stored, processed or be fed to fish.

5.1.5 Summary of life cycle

1. Adults are productive after 2-4 days and can deposit eggs 2 days after mating.
2. Eggs needs 4-5 days to develop.
3. Larvae needs 14-28 days to grow, average 22-24 days.
4. Pupae needs 14 days to develop to adult.

5. Life cycle time varies between: 35 - 52 days, average 40-44 days.
6. Life cycle time depends on type of feed, temperature, relative humidity and production speed.

5.2 Elemental Requirements for Cultivating BSF

This section provides a detailed picture of the the requirements for rearing BSF, which include: climate conditions, resources and breeding process.

5.2.1 Temperature, humidity, light and air flow

The minimum temperature for breeding BSF is 15 degrees centigrade. Optimal temperature range for the germination of eggs is 26-30 degrees centigrade at 70% RH (relative humidity). Optimal 27 degrees centigrade at RH 60 - 90%.

Optimal range for BSF larvae growth is 28-30 degrees centigrade at 65-75% RH. However, larvae will grow between 27-33 degrees centigrade but not as vigorously. Above 30-36 degrees centigrade growth of large would be reduced and it would stop as temperatures hit 36 degrees centigrade. The larvae should be kept in a dark environment. Larvae can tolerate lower temperatures because the heat generated by them during their growth phase would sustain them.

Pupation can take place at RH of 60% but with some air flow is needed to provide enough oxygen.

BSF have to be exposed for 12 hours per day to (day) light. The minimum radiation exposure for the flies to mate and lay eggs is at least 70 micromoles/m2/s. Optimal radiation exposure for the flies is 100-200 micromoles/m2/s. Optimal wavelengths of the light is 450-700 nm. Artificial light sources can be used to substitute daylight. It is recommended that the artificial lamps have the following specifications: 500 W 135 micromoles/m2/s quartz-iodine lamp.

Air flow is required to get the flies mating. This can be obtained by an electric fan or from natural sources.

5.2.2 Climate Profiles of BG Target Areas

The map below presents with the three BC Program regions (The map has been taken from the BG Innovation Fund web page).

Fig. 3 Blue Gold Catchment Area

Climate data has been obtained from weather database (average data over years) and from local input (only year 2016). The temperature and humidity are the most important climate data. The figures are shown below.

Regarding the temperature, the boundaries has been chosen between 15 and 33 degrees centigrade. However, the 15 degrees centigrade is the minimum temperature and far from optimal. The optimal growing conditions are between 26-33 degrees centigrade, as mentioned above.

Temperature and humidity profiles are provided below. Humidity data for Satkhira were not available; however, the humidity data for Khulna would be representative of Satkhira given their geographical proximity.

Satkhira

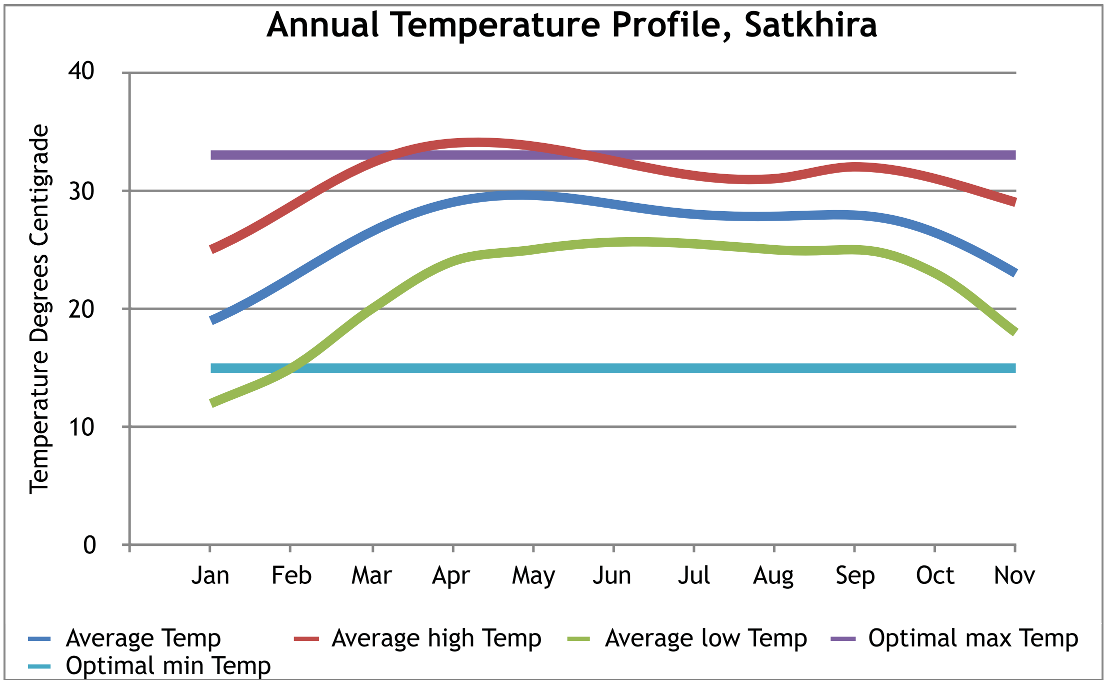

Fig 3.1 Temperature Profile of Satkhira (Note: Humidity Data not available)

Khulna

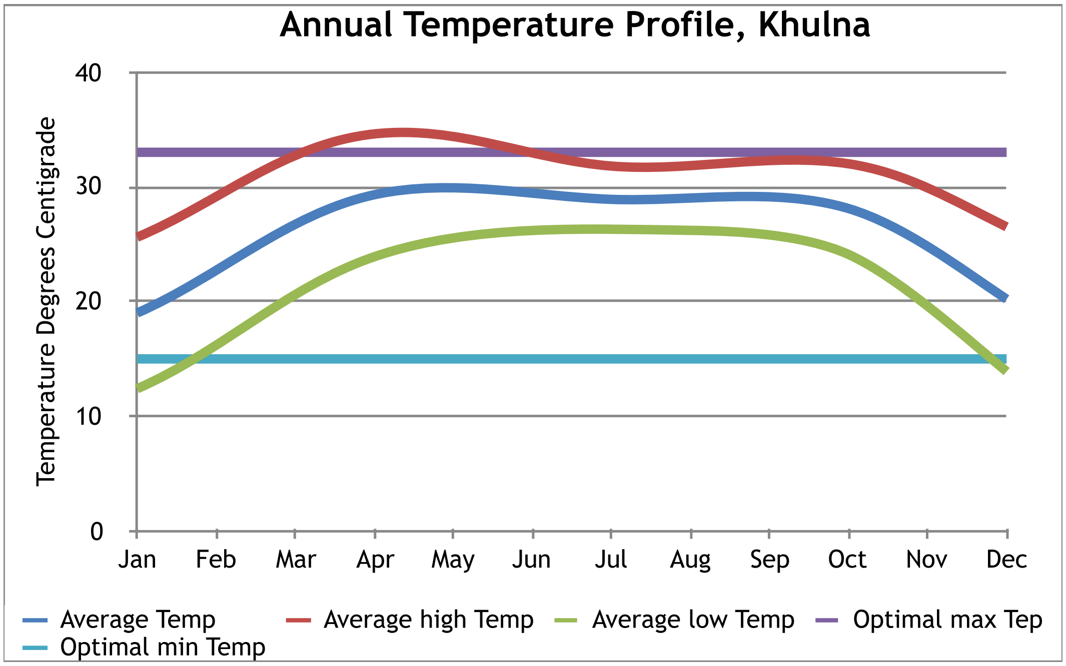

Fig. 3.2 Temperature Profile of Khulna

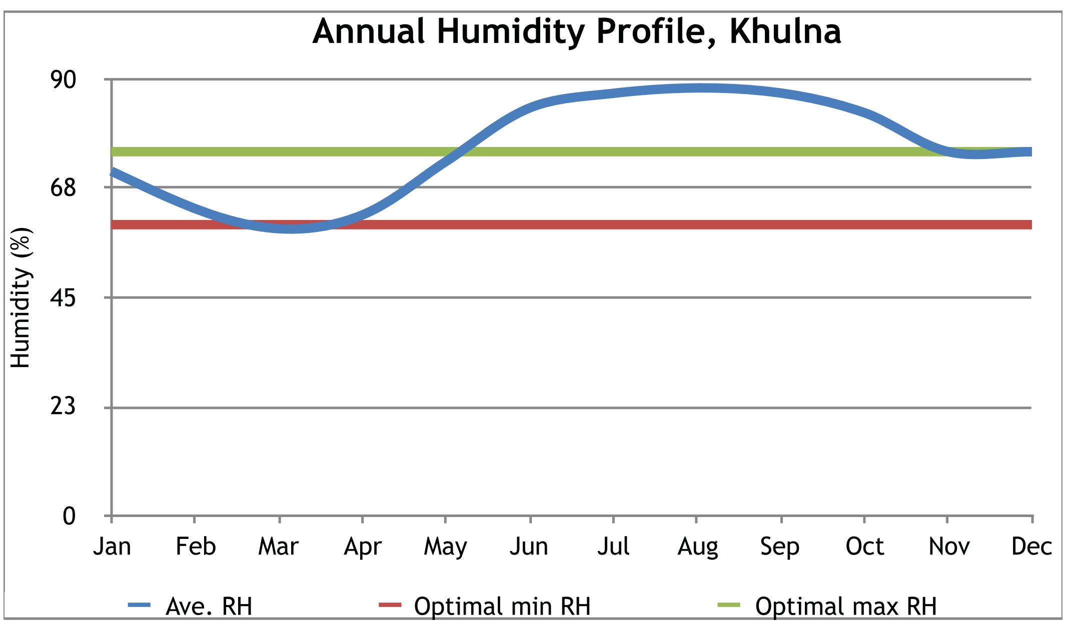

Fig. 3.3 Humidity Profile of Khulna (2016)
(Note: The interpretation of the humidity is quite complex due to the strong relation to the temperature)

Patuakhali

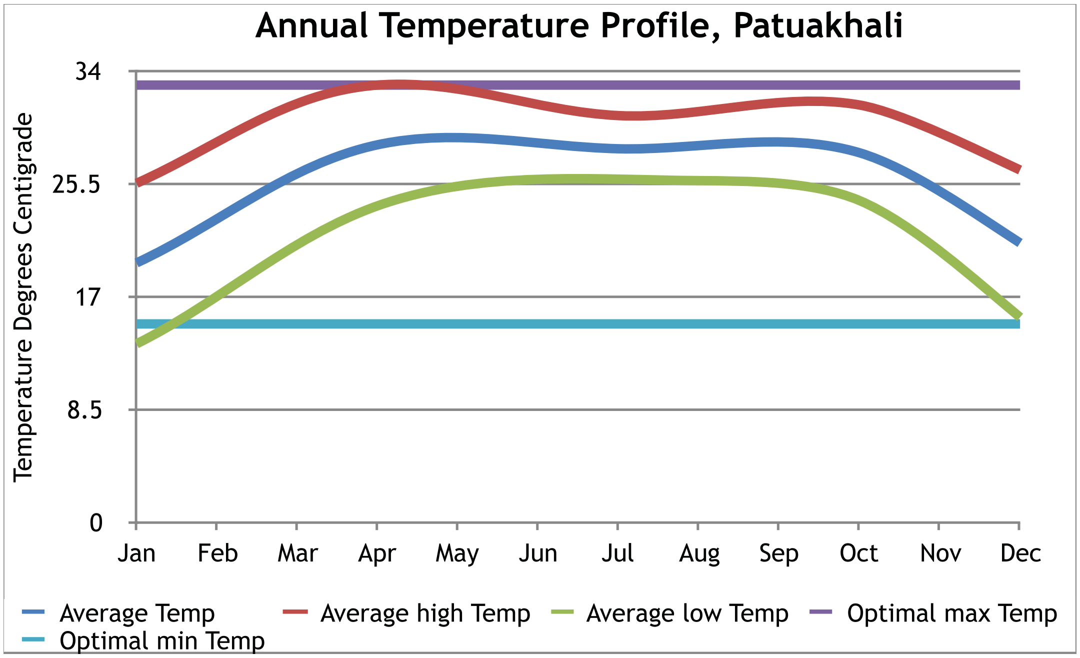

Fig. 3.4 Temperature Profile of Patuakhali

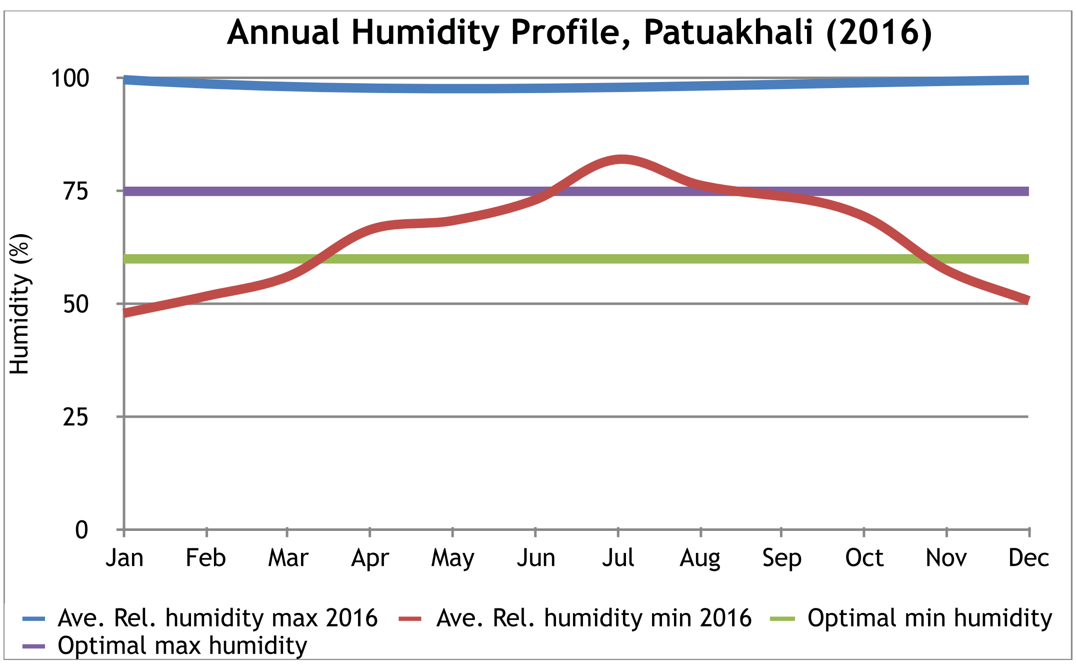

Fig. 3.5 Humidity Profile of Patuakhali (2016)

5.2.2.1 Conclusions

The climate conditions, which includes temperature and humidity, in the three BG regions are very well suited for rearing BSF. In order to ensure that BSF are properly cultivated, measures should be implemented to ensure that the temperature does not drop precipitously in a short period of time. Given the geographical location of Khulna, the risk of large temperature drops during the night is quite small.

Given on the local climatic conditions, it would be possible to rear and cultivate BSF without any active heating system. However, this is dependent on the expected temperature fluctuations and the temperatures during the winter season, particularly in December and January.

Since the larvae produce heat during as they consume detritus and grow, falls in temperature may not be too much of a concern because of residual heat generated by the larvae would be sufficient for them to survive through the sudden drops. However, some measures should be implemented to manage the retention and dissipation of the residual heat. Dissipation of the heat is also quite important because the larvae may be negatively affected if the temperature exceeds 30 degrees centigrade.

The humidity is strongly dependent on temperature. Data from Patuakhali and Khulna, strongly indicates that the humidity levels are extremely high. It is unknown if this might affect the breeding in a negative way. Normally, a low humidity stops the efficient grow.

5.2.3 Resources for Rearing BSF

Cultivating BSF requires some resources. Details of the resources requirements are provided below.

5.2.3.1 Feed for the BSF

BSF larvae thrive on detritus. The larvae are not very selective and they will vigorously consume animal and human excrements, and other organic waste (such as restaurant waste, kitchen waste, rice straws). Feed matter can be reduced by unto 50 per cent by growing larvae. Studies have demonstrated 45,000 larvae can consume 24 kg of swine manure in 14 days (citation).

The composition of the waste has an effect on the nutrition content of the larvae. Larvae fed on waste from slaughter houses and fish offal have a higher concentration of healthy omega-3 fatty acids which are very good for fish. Therefore, a mixture of different types of wastes will ensure that the larvae have a balanced nutritional value.

Yields of BSF larvae vary depending on their feed. Researchers have been able to harvest 50-185 g of larvae /kg of waste depending on the composition of the waste. Feed consisting primarily of rotten vegetables have yielded about 133 g of larvae / kg of waste.

Lignin (lignocellullosic) rich waste such as grass or cellulose should not be fed to the larvae as it may hamper growth. When the larvae are fed on excess organic waste they grow very quickly and they have a high survival rate. However, less waste is converted by them. The BSF larvae can also consume mouldy waste; however, they become lethargic which negative effect on their growth.

5.2.3.2 Water consumption

Optimal moisture content of the feed should range between 60-90%. This is critical for a proper growth. The BSF needs some water, which can be provided by spraying mists. The mist gets deposited as small droplets which can be absorbed by the BSF.

5.2.3.3 Substrate for eggs

It is important to have a good substrate to stimulate the production of eggs. The smell of the detritus attracts female BSF. However, the females do not deposit their eggs directly on the waste matter. Instead, female BSF lay their eggs on dry matters very close to the waste. In order to stimulate the female flies to lay their eggs, cardboard or flute pieces must be placed above or close by the detritus. The cardboard or flute pieces has to be changed regularly, because pre-existing pheromones on them will discourage female BSF from laying eggs on them.

Breeding units need a mixture of rotten kitchen waste, mustard oil cake, wheat (best for attracting female BSF), rotten vegetables, saturated brown-sugar solution and the cardboard pieces to ensure that the flies mate and lay their eggs continuously.

5.2.4 Breeding process and continuing the life cycle of the BSF

Before the BSF larvae can be cultivated and processed as fish feed, an initial population of BSF, which will provide the brood stock, is required.

There are two options to start with an initial population. The first option is to bring cultivated BSF pupae from a country (the Netherlands). There are some risks and complications with this approach because bringing a living organisms from one county to another involves dealing with customs and administrative issues, and raises environmental issues about its impact on the native species.

Alternatively, it is possible to collect the BSF species that are native to Bangladesh. This is less risky because there would be no administrative issues involving importation of a foreign BSF species. The primary advantage of this method is that the native BSF species are familiar with the climate conditions, environment and the locally available feed. There is a possibility that some other insects may be collected when the first brood stock is captured from the wild; however, it is possible to reduce the number of unwanted insects in the initial brood stock. Once a few generations of BSF are produced, this should not be an issue because the conditions would be optimised for the development of BSF, which would mean that BSF will out compete the infiltrators relatively quickly.

Capturing BSF from nature would fist involve building a trap. The trap would be a drum filled with rotten vegetables and other organic waste, and holders for the female BSF flies to lay their eggs. The eggs would then be collected and then used to create the brood stock that will form the basis for cultivating more BSF.

Once these eggs hatch they would be fed on waste matter to help them grow. Once the larvae reaches its pre-pupae stage it will migrate out of the feeding matter, when they will be collected. These pre-pupae would be allowed to pupate into adult BSF flies because they would be used in breeding units to harvest more eggs and restart the life-cycle of the flies.

The pupae will be added to the wood chips below the adult breeding unit. When pupae emerge as adults, they will be encouraged to fly into a designated area with the help of air flows, generated either artificially or naturally, where they will be encouraged to mate with other BSF and lay eggs.

The eggs will be harvested regularly from the breeding units and put in a box with the substrate (organic waste). In this way, the size and stages of the larvae can be monitored so that they do not have to affect each other’s growth.

5.3 Mass Balance and Processing

This sections provides detail calculations about the yield of larvae that can be expected when BSF are reared. Additionally, the section will set out how the lava can be processed so that they can be utilised most effectively by the fish which will be cultivated.

5.3.1 Mass Balance

There is a large variation in the mass balance calculations, because of the wide range in the amount of substrate (biomass or organic waste) that BSF larvae can consume. These calculations provide a base line about the expected yield of larvae and protein. The following assumptions have been made for the purposes of this report.

It has been assumed that one BSF larvae would consume about 150 mg of waste/day on average. Additionally, each holding pen for rearing the larvae will have dimensions of 1 m X 1 m, i.e., area of 1 $m^{2,}$ and it will hold about 50,000 larvae. The larval stage has been assumed to last for 25 days (on average). After each cycle the box will be cleaned and reused again. Therefore, each box will can theoretically sustain about 15 larval cycles of BSF during the course of 1 year. Average life cycle of the BSF, as a whole, is 44 days, which includes all stages of development from eggs to adults. The life cycle and the rearing of larvae can be managed so that the larvae can be grown continuously throughout the year.

Summary of key assumptions

- Approximately 900 kg of substrate (organic waste) is required per year for a 1 m^2 box of BSF larvae.
- Each holding box will have about 50,000 BSF larvae (approximately).
- It will yield approximately 150 kg of wet BSF pre-pupae per year.
- The feed conversion ratio has been assumed to be about 18 per cent (Note: The feed conversion ratio refers to the amount of feed that is converted by the larvae into usable biomass. It has also been assumed that 50 per cent of the waste (biomass) has been converted to larvae castings, and has been used by the larvae to keep itself alive.)

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Mass Balance

Item	Specifications	Amount	Unit
No of BSF Larvae	Dimensions: 1m X 1m	50000	per box
One Larval Cycle			
Duration		25	days
Feed requirement		150	kg/per cycle
Yield of larvae		10	kg/ per cycle
Dry larvae yield	50%	5	kg/ per cycle
Protein content	41% (approx)	2	kg/cycle
Annual			
Larval life-cycles		15	
Feed requirement		2250	kg/yr
Yield of larvae		150	**kg/yr**
Dry larvae yield		75	kg/yr
Protein content		31	kg/yr
Feed conversion		15	per cent
Dry larvae yield/mth		6.25	**kg/mth**

Fig. 4 Mass Balance Analysis (approximations) for one larvae holding pen of 1 m^2

5.3.2 Processing BSF larvae as fish feed

There are multiple ways the BSF larvae can be processed for use as fish feed. However, the optimal method for processing the larvae would depend on specific requirements, such as the stage of development of the cultivated fish, they species of fish and the propensity of farmers to engage in manual work.

Ways in which the larvae can be fed to fish include, providing live larvae to the fish or drying the larvae, by dehydrating them, before feeding the fish. In the first case the size of the fish is important because only larger fishes will be able to consume the whole larvae. If the fish is quite young, the larvae would have to be chopped in small pieces before they are fed to the fish otherwise they may be unable to eat them.

In the latter case, before drying the BSF larvae they would have to be killed in hot water (or in a hot oven). There are two reasons for this: kill the larvae and eliminate bacteria. Then the larvae can be dried in an oven or in the sun. Dried larvae can be preserved for a longer period of time than the live larvae, which would allow the farmers to stock up BSF larvae. Additionally, the dried larvae can be ground to a powder and then mixed with other fish feed, such as comical fish feed, mustard oil cake or other non-commercial fish feed, in varying proportions depending on the fish a farmer is cultivating.

The optimal processing procedure for the fish farmers of the BG target areas will be determined during the pilot because different fish farmers have different feed requirement. This customisation is essential for farmers to maximise their yield of fish.

5.4 Conclusions

This section has provided detailed explanations and analysis of the life cycle of the BSF, the ideal conditions for rearing them, the resources that would be needed to cultivate BSF and its larvae, the expected yield of larvae (based on specific parameter) and post harvest processing of the larvae into fish feed. Analysis of the climate data strongly indicates that the environment is suitable for the cultivation of BSF and its larvae. The mass balance calculations indicate that farmers would be able to produce a significant amount of BSF larvae from each box per year.

It is submitted that further exploration of this technology is highly merited because it can potentially obviate one of the largest constraints on the growth of aquaculture in the BG target area. The next section explore the different business model that can be adopted to ensure that the use of BSF larvae as fish feed can become a reality.

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6. Business Model

The use of BSF larvae as an alternative fish feed is already a proven concept. A number of companies all across the globe (such as in China, Indonesia, USA, South Africa) are already working on large scale operations. There has been an initiative in Ghana where small scale BSF larvae production facilities have been tested.

In general, we have two options for the business model of breeding BSF for fish farmers: Small-Scale *decentralised* facilities and large-scale *centralised* facilities. This sections analyses the merits of both the decentralised and the centralised model, and concludes which would be the most effective approach for developing the use of BSF larvae as fish feed given the market conditions in the areas where BG operates.

6.1 Decentralised BSF production facilities

Decentralised facilities involve segregating the production of larvae. This involves two broad divisions: breeding the insects, collecting the eggs and hatching them; and growing the larvae and processing them. The breeding units will be operated by Aspire and its partners because this requires some specialised know-how and close monitoring of the environmental conditions. The BSF are quite picky when it comes to laying their eggs in captivity. If the environmental conditions are not properly managed, the BSF will not mate; meaning, that the larvae production will be hampered.

In contrast, rearing the larvae is a relatively straight forward operation which would be quite suitable for the farmers in the BG target area because of their limited education background and expertise.

The breeding units will be operated in an area where the conditions are most favourable for the BSF. Separating the breeding units will ensure that Aspire and Insectsforall are able to monitor the brood-stock and ensure that there is always a regular supply of eggs available for fish farmers. The eggs will be supplied to farmers with detailed instructions about how to rear them until the larvae is ready to be used as fish feed. Each farmer can operate his larvae rearing operation on site, which means that they would not have to travel far to obtain fish feed.

Separation of breeding and rearing is important because of poor infrastructure in the southern regions of Bangladesh. Since electricity is needed to ensure proper air circulation within the breeding units, breeding units can be set up in areas where there is reliable electricity connection. As growing the larvae does not require any resources apart from organic waste, farmers would be able to grow their fish feed in any location in the BG target area because the climate conditions play the primary role for the growth of the larvae.

The farmers would be required to accumulate organic waste which will be needed for growing the larvae. From the interviews that have been conducted, it has become clear that fish farmers in the BG target area do not process their household organic waste. Operating larvae rearing facilities, thus, will enable fish farmers in the BG target area to extract value from their household and other organic waste. Farmers have the option of harvesting pre-pupae larvae (or the larvae before they reach the pre-pupae stage) for feeding their fish. Further investigations is needed to determine which would be optimal given the market conditions of the fish farmers in the BG target area.

Further exploration is also needed in relation to the optimal approach for processing the BSF larvae before they are used as fish feed. Various options will be explored in the pilot. These include: feeding live larvae to fish, feeding chopped larvae to younger fish, feeding dried larvae to the fish (as whole larvae, chopped larvae and powered larvae).

This model will enable fish farmers to save money, because they all be able to partially or completely substitute commercial fish feed with by BSF products. Farmers will also have the option to sell the worm castings as high quality organic fertiliser or use that by product to fertilise the soil for their own agricultural production.

Aspire and Insectsforall will provide BSF recently hatched larvae to the fish farmers, and technical training and support for rearing the larvae. Thus, Aspire will be able to generate revenue from selling young larvae and offering technical assistance. Since the nutritional composition of the larvae are dependent on the waste upon which they are grown, farmers would need guidance in relation to what waste they should use to rear their larvae that would be consistent with the specific needs of the fish they cultivate. Farmers, consequently, would have unprecedented control over the compositor of the fish feed, thus enabling them to customise their feed to their specific requirements.

Given the novel nature of this operation, the decentralised model would provide an ideal starting point before moving to centralised operations. The merits of the both of these approaches are compared below (see section 6.3).

6.2 Centralised BSF Production Facilities

Centralised BSF production facilities is a natural progression from the decentralised production model. After the breeding facilities become operational Aspire and Insectsforall will expand to incorporate a larvae rearing facility, waste processing facility and processing facility. This would be the most prudent approach because this involves accretion, i.e. growth through addition of new facilities to the ones that already exist.

Adding new facilities to the already existing breeding facility will ensure that the contracting parties already have a presence in the community and they will also have sufficient data to fine tune and enhance the larvae production and harvesting. Large scale larvae production facilities will be helpful because it will enable the contracting parties to achieve economies of scale which will enable the production of insect larvae based fish feed more efficiently.

Since, it may not be profitable for large scale fish farming operations to produce their own larvae production facility because that would be outside their realm of expertise. Large scale aquaculture operations may stand to benefit more by purchasing larvae based fish feed directly from Aspire and its partners because that would enable them to focus on the expertise, namely, the production of fish. The large scale centralised operations will significantly benefit farmers because they will be able to access high quality fish feed at very competitive prices because the inputs for the larvae production facilities do not have much economic value and these can be sourced locally. This means that the inputs are not susceptible to price fluctuations in the international market. Additionally, economies of scale would allow the production of large volumes of fish feed at competitive prices for the foreseeable future.

Since the centralised BSF facility can be based in any part of Bangladesh which has access to reliable electricity (although this is not an essential criteria because the process does not require a huge amount of electricity), it would be possible to set up these facilities all over the country. New facilities could be set up within a year or two of setting up the decentralised BSF production facility because by that time all the challenges of an integrated larvae production facilities will have been addressed.

These facilities can be set up in areas where there is a high concentration of fish farms, because the inputs for the farm (i.e. organic waste) can be sourced from anywhere and the production process does not require a huge amount of electricity. From a mass balance and transport perspective it may be more efficient to locate the centralised facilities near depositories of organic waste and then transport the final product (BSF larvae based fish feed) to the desired location. Where electricity supply is unreliable, alternative sources of generating power, such as solar or diesel generators, can be used.

This operation will generate jobs in the BSF farm and give trainings and education to the employees. Additionally, it will ease the pressure on local communities to find a safe landfill for all their organic waste; thus reducing the risk of contamination of their ground water and usable land. Finally, research facilities on these sites, which will also be set up as part of the large scale facilities, will help to improve the efficiency of the production methodologies and explore other local insects which could also be utilised as fish feed or animal feed.

Aspire and its partner will play a major role in the organisation and operation of these facilities, which will include enforcing and designing commercial agreement for the acquisition of land, processing and acquiring of organic waste; develop methods for packaging and distributing the larvae based fish feed. Recently, the EU has passed legislation that allows the use of fish feed produced from insect larvae. This could provide a signifiant new market for the contracting parties, because the climate conditions of Bangladesh are very suitable for the production of insect, and thus allow Bangladesh to develop a new export product.

6.3 Decentralised Facilities vs. Centralised Facilities

The main reason for focusing on the decentralised model for rearing BSF larvae is management of risk. Segregating the breeding and the rearing of BSF flies will ensure that the challenges of developing and maintaining the brood stock does not have to be handled by farmers who may not be very inclined to keep detail records of the processes to identify inefficiencies in the production process. Additionally, by delegating the larvae growing phase to the farmers, they will be able to significantly reduce their feed cost because the cost of rearing BSF larvae would be substantially lower than traditional feed. They could use their household waste and other organic waste to rear the larvae, thus utilising previously unused resources. Finally, they will be able to use the larvae castings to fertilise their fields reducing their dependence on commercial fertilisers or sell it on the market to directly supplement their income.

Engaging the farmers in this way will give them a stake in ensuring the success of the project because they will be able to directly benefit from the new technology. Since many farmers of the BG target area can participate in the rearing the larvae, multiple larvae rearing facilities can be set up within the BG target area during the pilot phase. This will create many sources to data which can give more detailed picture of the benefits of using larvae as an alternative fish feed. From an administrative point of view, ensuring that there is one breeding facility for BSF will ensure that the BSF are properly managed because the most challenging part of the project is to ensure that the flies mate and regularly deposit their eggs.

The focus of the pilot phase will setting up an operational breeding unit that will be operated by Aspire and multiple larvae rearing facilities which will be operated by the BG farmers. Once the eggs are collected from the breeding facilities, they can be hatched before they are handed over to the BG farmers to rear them on waste materials. Once the larvae has reached maturity they can either be harvested before the pre-pupae stage or they can be harvest during the pre-pupae stage. The choice of collecting the harvest depend on a number of things which include: labour requirements and nutritional value of the larvae.

Once the pilot phase is complete, the data will help Aspire and Insectsforall to make customised recommendations to help farmers increase their production and thus help them reduce their reliance on commercial fish feed. Scaling up the project will then require adding a larvae production facility, a holding facility for organic waste and research facility on the already established site. This will mean that the most of the resources used for the pilot phase can be utilised for the commercial project.

In the long term, the information and expertise gathered from the implantation of micro BSF production facilities can form the basis for scaling up the project to a centralised production facility. The objective of that project would be to provide high quality and competitive fish feed to large commercial fish farming operations that exist in other regions of Bangladesh.

6.3.1 Advantages of Decentralised BSF Facilities

The key advantages of the setting up micro BSF facilities include:

1. Hedging risk, so that the project can be managed more effectively and improve the chances of timely completion;
2. Most efficient allocation of the resources that are available for the pilot;
3. Lower operational cost because the BG farmers will be operating the facilities in addition to their other agricultural activities;
4. Detailed oversight and monitoring of the most crucial and delicate phase of BSF life cycle;
5. Encourage participation of the BG farmers because they will be able to benefit directly from the project;
6. Accumulating waste would be more economical because farmers could use their organic waste that they generate themselves or slaughter waste from fish for rearing the larvae;
7. Extraction of value from waste will reduce the waste generated by the BG fish farmers and thus reduce the pressure on the delicate ecosystem of the areas in which BG operates;
8. Farmed fish will be fed on more nutritious feed, thus enabling the BG farmers to increase their yield;
9. Reduce the reliance of farmers on commercially available feed whose quality are sometimes suspect;
10. Improve participation by women in the BG target area because larvae rearing does not require lifting heavy weights;

11. Much easier to train farmers to rear the larvae because these are very robust, which means they will survive even in sub-optimal conditions;

12. Provide valuable data for scaling up the project; and

13. Scaling up the project will require adding new units to already existing structures.

6.4 Points of attention

Although the use of BSF larvae as fish feed has a huge potential realising the potential requires a lot of hard work, particularly because insect larvae has never been reared commercially in Bangladesh. Few essential things that should be born in mind during the pilot phase include:

1. Initial capital outlay for a breeding farm is relatively high

2. Space is required to develop and maintain the brood stock, and ensure that they propagate continuously and regularly,

3. Time may be needed to ensure that all the challenges associated with the copulation of BSF and collecting their eggs are resolved,

4. Maintenance of the breeding facility requires substantial organisation to reduce the risk of diseases affecting the BSF brood,

5. Educating and monitoring the farmers as they rear the larvae before they are used as feed requires organisation and regular supervision,

6. Precise nutritional composition of the larvae baed on the composition of the biomass on which the larvae are fed, and

7. Developing the value chain of BSF larvae based fish feed on a commercial scale will require some time and organisation because it would involve negotiating commercial agreements and training skilled staff

6.5 Conclusion

Despite the challenges, the analysis of the different business models provide a strong basis for initiating the project. The model provides a through analysis of the challenges that can arise in relation to the implantation of BSF larvae based fish feed and has provided a detailed strategy to deal with those issues. By focusing on the decentralised larvae rearing facilities and one breeding facility the pilot phase will form the foundations for commercialising the project. The next section will provide details cost benefit analysis, in order to make a strong business case for developing the decentralised BSF production facility.

7. Business Case for Commercialisation

On the basis of research and analysis, it is submitted that using BSF larvae as an alternative fish feed is technologically and practically possible. However, in order to make a sound business case for this technology, the economic aspects has to be addressed as well. Given the risk involved in developing the technology, the focus of this section will be the decentralised model (discussed in section 6).

A sound business case for the decentralised model involves doing detailed financial analysis. This section will provide details about the following issues in support of the decentralised model:

1. Projected cash flow/income from the breeding facility that will be operated by the contracting parties and the rearing facilities operated by the fish farmers in the BG target areas;

2. Projected costs for setting up one breeding facility and one rearing facility; and

3. Cost-benefit analysis in relation to the implementation of the chosen business model.

Analysis of the business case for the centralised model will be excluded, for the moment, because of the higher exposure to risk associated with this model.

After the completion of the pilot, the contracting parties will assess any deviations from the estimated figures. Based on the data based assessments after the pilot, the contracting parties will re-analyse the optimal approach (decentralised vs. centralised) for commercialising the technology. It is submitted that both business models can be utilised for commercialising the project in the future. However, staring off with the decentralised model would allow the contracting parties sufficient data and experience to implement the centralised business model much more efficiently.

7.1 Assumptions

Since no benchmark is currently available, given the novel nature of the project, few assumptions had to be made to make the business case. The assumptions have made these on the basis of literature and field research to ensure that they are representative of the market conditions in the BG target areas. Assumptions for the projected investment costs and projected income are provided below.

7.1.1 Assumptions for CAPEX (Capital Expenditure) and OPEX (Operational Expenditure)

1. Cost of constructing the various units (in the future) incorporates land associated costs.

2. Fully operational breeding facility incorporates three structures: one for breeding, one for processing the larvae and one for storing the substrate (biomass). The processing units incorporate the cost of larvae rearing pens to produce BSF, which will be used to produce the larvae that will be supplied to the rearing facilities.

3. Breeding unit will have cages of volume 1 m^3 and each cage will be able to house 3000 flies.

4. The capacity for a fully operational breeding facility has to be about 3 tons of larvae per cycle (i.e. 24 days) so that it can supply larvae for about 50 rearing facilities. This is based on the assumption that average weight of 1000 eggs is 10 mg.

5. The breeding facility will need to about 70 tons of biomass per year (i.e. approximately 7 tons of biomass per month) when it will be operating at its optimal capacity.

6. This is derived from multiplying the amount of biomass needed per cycle with the number of expected cycles per year.

7. A rearing facility for a farmer includes two structures: one for rearing the larvae and one for storing biomass.

8. Fish farmers in the BG target area are able to replace un to 75% of their commercial fish feed with BSF larvae, and they are engaged in cultivating fish in one hectare.

9. The rearing facility will have a capacity to produce 1.5 tons of dry larvae fish feed per year (when it is fully operational in the future), meaning the facility would need to operate 20 larvae rearing boxes (each box producing about 75 kg of dry larvae per year). 1.5 tons of BSF larvae based feed will be needed to supplement 75% of the commercial fish feed required to cultivate fish per hectare of water in the BG target area.

10. Measuring and handling devices include thermometers, shovels, carts, humidity meters, weighing scales (large and small), fans, tarpaulins for covering breeding units to reduce heat loss at night, etc.

11. Given the biomass conversion rate of 15% by the BSF larvae, it is estimated that the rearing facility would need about 30-40 tons of biomass every year (i.e. about 3.3 tons per month) to operate at its maximum potential.

12. Staff costs for the breeding facilities are higher because operating that facility requires skilled labour such as managers, technicians and laboratory technicians.

13. Staff costs for rearing facilities are much lower because it is assumed that the farmers will be rearing the larvae by themselves and the work involved does not require specialised skills.

14. Disposable costs include the cost of consumables, such as gloves for handling the larvae, gas for heating water, spoilage, etc.

15. Monitoring the production cycles of both rearing and breeding facilities, data collection and data analysis are essential for fine tuning the larvae production and rearing techniques. So, research and development would be a key element of operating the breeding facilities.

16. Capital depreciation is excluded from OPEX because it has no effect on the cash flow.

7.1.2 Assumptions for Earnings

1. 50,000 young larvae is considered to be one unit because that is the amount of larvae that can be grown in an 1m X 1m box;

2. The price for one unit of young larvae has been estimated to be 140 BDT;

3. The breeding facility will also be able to benefit from the sale of larvae casting at 5 BDT/kg (the price is estimated on the basis of the price for worm castings, i.e. vermicompost, in Bangladesh);

4. Breeding facility will be able to supply larvae for about 50 small rearing facility, which means that the breeding facility has to produce about 1000 boxes of larvae units per cycle, i.e. 1250 boxes of larvae per month;

5. It should be noted that the protein content of commercially available fish feed is about 20% (allegedly) which is about half of the protein content of the BSF larvae based feed. Benefit to farmers on the basis of protein content of BSF larvae based fish feed would be substantially higher because it has about 40% protein content. Therefore, fish farmers would need be able to substitute 2 kg of commercially available fish feed with 1 kg of BSF larvae based feed. Assuming that the fish farmers substitute 75% of their commercial fish feed with BSF larvae based feed, estimated cost savings (i.e. benefit) for the fish farmers

would be about (75% of 2 kg) 1.5 kg of commercial fish feed. This means that net benefit from larvae based feed will be about (60 BDT X 1.5kg) 90 BDT/kg. (This benefit is based on the price of floating commercial feed that is available in the market, which is 60 BDT/kg at 20% protein content).

6. The yield of the dry larvae are taken from the mass balance calculations (75 kg of dry larvae per cycle would lead to the production of 1.5 ton of fish feed per year by a rearing facility which has 20 larvae rearing units); and
7. Yield of the larvae castings are taken from the research trials which indicate that about 50% of the biomass can be harvested as larvae castings. This would apply for both the rearing facility and the breeding facility.

7.2 Projected income

The decentralised model for implementing the technology of producing fish feed from BSF larvae will segregate the chain of production into two parts. One part will be focused on the production of larvae and the other part will be focused on rearing the larvae and processing them for their fish.

Larvae production at the commercial scale will be carried out in the breeding facilities which will then be sold to the larvae rearers in the BG target area. Therefore, the primary source of the income for the breeding facility will be the sale of the young larvae.

Sale of the larvae castings can offer a valuable source of income for the breeding and the rearing facilities. It should be noted that there is no comparable price of the larvae castings at the moment. An accurate indication of the price would be obtained during the pilot.

The chart below demonstrates that expected earnings for a breeding facility that would be able to supply young larvae to 50 small and medium sized rearing facilities with (up to) 20 rearing units.

Projected Income: Breeding Facility

Items	Earnings (BDT)	Earnings (EUR)	Notes
Every production cycle			
Earning from sale of larvae	140,000	1,474	For details see section 7.1.2
Every Month			
Sale of young larvae	175,000	1,842	Earnings for 15 cycles divided by 12 months
Sale of larvae castings	15,000	158	See assumptions at 7.1.2
Subtotal	190,000	2,000	
ANNUAL TOTAL	2,280,000	24,000	

Fig. 5.1 Projected income for Breeding Facility

The next chart provides the income (i.e. benefit in kind) that the farmers who rear the larvae would be able to realise when this technology is commercialised. The rearing facilities are estimated to produce 1.5 tons dry larvae annually and 24 tons of larvae castings. The farmers can choose to use the outputs of their rearing facilities for their personal use; however, they could also opt to sell their outputs in the market.

Projected Income: Rearing Facility

Items	Earnings (BDT)	Earnings (EUR)	Notes
One Box of Larvae per production cycle			
Benefit from larvae based fish feed	450	5	For details, see 7.1.2
Earnings from larvae casting as organic fertiliser	375	4	See section 7.1.2

Projected Income: Rearing Facility

	Earnings (BDT)	Earnings (EUR)	Notes
20 Boxes of larvae per Annum (15 cycles)			
Benefit from larvae based fish feed	135,000	1,421	See section 7.1.2, for details
Earnings from larvae casting as organic fertiliser	112,500	1,184	(As above)
AUNNUAL TOTAL	**247,500**	**2,605**	

Fig 5.2 Projected Income for Rearing Facility

7.3 Projected Costs

This project requires some initial capital investment because breeding BSF and rearing them for use as fish feed, requires the construction of dedicated facilities in which the BSF are bred and reared. Since the chain of production is segregated, the breeders do not have to bear the cost of setting up large number of rearing units and the rearers do not have to invest in setting up and managing a breeding facility. This significantly reduces the up-front capital investment and operational cost for the farmers in the BG target. Additionally, this approach makes this technology more accessible to the target farmers because rearing BSF larvae is much simpler than breeding them. Once the farmers are adept at rearing BSF, they could expand in to breeding them, in which case the contracting parties will support them as much as possible.

The charts below set out the capital expenditure (CAPEX) and operational expenditure (OPEX) for both the rearing facility and the breeding facility.

Projected Capital Expenditure: Breeding Facility

	Costs (BDT)	Costs (Euro)	Notes
CAPEX-B (Breeding Facility)			
Breeding Unit	400,000	4,211	For details see section 7.1.1
Processing Unit	400,000	4,211	(As above)
Biomass Storage Unit	200,000	2,105	(As above)
Wooden Cages	80,000	842	(As above)
Electrical equipments	60,000	632	(As above)
Measuring and Handling Devices	100,000	1,053	(As above)
Administrative licences	20,000	211	
TOTAL	**1,260,000**	**13,263**	

Fig 5.3 Projected CAPEX-B (Breeding Facility)

Projected Capital Expenditure: Rearing Facility

CAPEX-R (Rearing Facility)			
	Costs (BDT)	**Costs (Euro)**	**Notes**
Larvae growing boxes	50,000	526	If the boxes are rented the cost would be substantially lower
Rearing Unit	40,000	421	
Biomass Storage Unit	10,000	105	
TOTAL	**100,000**	**1,053**	

Fig 5.4 Projected CAPEX-R (Rearing Facility)

Projected Operational Expenditure: Breeding Facility

OPEX-B			
Costs per month	**Costs (BDT)**	**Costs (Euro)**	**Notes**
Staff	100,000	1,053	See section 7.1.1 for details
Disposable costs (gloves, gas, spoilage)	10,000	105	
Electricity and Water	5,000	53	
Research and Development	25,000	263	
Substrate (Biomass)	8,000	84	
Contingency	10,000	105	
Sub Total	158,000	1,663	
ANNUAL OPEX-B	**1,896,000**	**19,958**	

Fig 5.5 Projected OPEX-B (Breeding Facility)

Projected Operational Expenditure: Rearing Facility

OPEX-R			
Costs per month	**Costs (BDT)**	**Costs (Euro)**	**Notes**
Staff	5000	53	See section 7.1.1 for details
Substrate (Biomass)	3,000	32	

Projected Operational Expenditure: Rearing Facility

Cost of young larvae	3,500	37	One month is equal to 1.25 cycles (approx)
Disposable costs (gloves, gas, spoilage)	3,000	32	
Contingency	1,000	11	
Sub Total	15,500	163	
ANNUAL OPEX-R	**186,000**	**1,958**	

Fig 5.6 Projected OPEX-R (Rearing Facility)

7.4 Cost Benefit Analysis

This section provides the profit analysis for the decentralised business model for producing BSF larvae based fish feed. Deducting the projected operational costs from the projected operational income, illustrates the profit that can be expected from operating a breeding facility and a rearing facility. Based on the expected profit, the section then demonstrates the expected time for recuperating the initial capital investments.

Expected Profit from Breeding Facility

Per Annum	(BDT)	(Euro)	Notes
Expected Earnings	2,280,000	24,000	See fig 5.1
(Less) Projected OPEX-B	1,896,000	21,726	See fig 5.5
Net PROFIT	**384,000**	**7,200**	

Fig 5.7 Expected Profit (Breeding Facility)

Expected Profit from Rearing Facility

Per Annum	(BDT)	(Euro)	Notes
Expected Earnings	247,500	28,421	See fig 5.2
(Less) Projected OPEX-R	186,000	21,726	See fig 5.6
Net PROFIT	**61,500**	**647**	

Fig 5.8 Expected Profit (Rearing Facility)

Based on these expected profits it is estimated the return on investments for the breeding facility and the rearing facility are given below. Return on investment is defined as profit divided by capital expenditure multiplied by 100%.

Return on Investments

Breeding Facility			Notes
Return on investment (%)	PROFIT from Breeding facility / CAPEX-B	30	See fig 5.7 ad fig 5.3
Rearing Facility			
Return on investment (%)	PROFIT from Rearing facility / CAPEX-R	62	See fig 5.8 and fig 5.4

Fig 5.9 Return on Investment

The numbers indicate that the fish farmers in the BG target area should be able to recover their capital investment within two years. It will take just over three years for the contracting parties to recover their capital investment because setting and operating a breeding facility is much more expensive then setting up and managing the rearing facilities. Although these numbers seem very promising, it would be wise to keep in mind that these calculations are based on assumptions. Nevertheless, it is submitted that further exploration of this technology is merited because it can offer the fish farmers of the BG target area a new source of revenue (i.e. sale of larvae castings) and substantial benefit in relation to the cost of fish feed.

8. Social and Legal Considerations

This section analyses the relevant legislation and the social issues that may arise in relation to the implementation of the using BSF larvae as fish feed and sets out how these challenges can be addressed.

8.1 Legal Aspects

The regulation for fish feed and animal feed in Bangladesh is governed by Animal Feed and Fish Feed Act 2010 (Act). The Act does not explicitly preclude the use of insect larvae in fish feed. Section 10 of the Act states "the Government shall determine the ideal value of the various ingredients of fish feed and animal feed by rule and follow the said values on compulsory basis during production of fish feed and animal feed on commercial basis."

Setting up Micro BSF facilities does not explicitly fall within the purview of the regulations because Aspire and Insectsforall would not be providing any fish feed, prima facie. This model facilitates fish farmers to create their own fish feed by providing them with the set up for rearing the BSF larvae, giving them advice on how to rear them and help them harvest the larvae which they can use to supplement their feed or use it as an alternative to commercially available feed.

Section 10 of the Act may be applicable when the contracting parties commercialise the project and if they choose to produce and package the feed for the fish farms. Even then, using BSF larvae as fish feed would fall within the regulations as long as the nutritional composition of the larvae based feed satisfies the set value of proteins, carbohydrates and other ingredients that are set out in the subsidiary legislation. Teaming up with a tertiary educational institution, such as a University, or Government Research Institutions may be helpful because they would be able to facilitate the nutritional analysis and organise the methodology for implementing the rearing facilities. However, their level of engagement would depend on available funds and their availability.

Provided that the larvae based feed do not contain any contaminants, such as harmful chemicals and antibiotics, there is no prima facie legal restriction. Although research has indicated that the larvae do not have any harmful materials, precautionary procedures can be incorporated to ensure that the larvae are properly sterilised so that no traces of their input, (namely, organic waste) on which they were reared, remain in their gut. Since the BSF larvae are very efficient in breaking down harmful bacteria and hazardous compound into inert matter, the final product will not have any compounds that would be harmful to the farmed fish.

In relation to the use of the larvae castings as organic fertilisers, the market is still largely unregulated.

8.2 Social Aspects

Given the novel nature of this project in Bangladesh, some initial concerns have been that consumers may be unwilling to purchase fish that has been reared on the larvae of insects and that fish farmers of the BG target area may be reluctant to use larvae based feed because of social stigma. In order to allay these concerns, Aspire and Insectsforall conducted a field study to gauge the interest of the farmers and potential buyers.

From the interviews it has become clear that the fish farmers of the BG target area do not have any issues in using fish feed produced from insect larvae. Their main concern for the farmers is the price and the quality of the feed that would be available to them for rearing their fish stock. The interviews indicate that the enforcement of the legislation is quite weak, and there is no standardised approach to feeding the cultivated fish. Many farmers use home made fish feed produced from various products, such as rice cake, de-shelled snails, husks, etc.

The fish farmers explained that the purchases of the fish are not really concerned about what is fed to the fish, provided that the fish are healthy and they have no contaminants in them. Although, there has been a lot of concern in relation to the use of formalin to extend the shelf life of fish at the expense of the heath of the consumers. These practices indicate that the primary motivations for using fish feed is the nutritional composition of the feed, which will enable the fish to grow quickly and remain healthy.

The interviews indicate that the aquaculturists of the BG target area are quite enthused about the project. They have shown a great deal of interest and they have indicated their interest in participating in the pilot.

The use of larvae casting as organic fertilisers would be socially acceptable because the use of earth-worm casting as organic fertiliser is well established practice in Bangladesh, which would mean that people are used to the idea of using castings as fertilisers. Furthermore, the reduced dependence on commercial fertilisers for agricultural production would mean that the cost of producing would go down allowing the farmers to obtain additional financial benefit. The farmers could also sell the casting as high quality fertilisers to supplement their income.

8.3 Conclusions

Field research and legal analysis demonstrates that there should be no legal and the social impediments to implementing the pilot phase and commercialising the use of BSF large as an alternative fish feed.

It should be noted that when the report was presented to the Blue Gold Team and members of the Government of Bangladesh, some concerns were raised. Chief among the concerns were:

1) Would the Department of Fisheries have any concerns about the use of BSF larvae as fish feed and whether the use of larvae as a substitute can be accommodated within the legal and regulatory framework?; and

2) Would consumers have any reservations about consuming fish that has been reared on BSF larvae?

As far as the current law is concerned, there is no restriction in relation to the use of BSF larvae as a component of fish feed. The trial conducted by the researches at the Agricultural University of Bangladesh indicate that supplementing fish feed with BSF larvae would be acceptable, given that the research was conducted with the support of the Government of Bangladesh. However, it is submitted that close co-operation and dialogue with the Department of Fisheries during the pilot phase would be essential to ensure that a coherent and viable policy for the development of BSF larvae as a component of fish feed.

Determining the reservations of consumers is a difficult because this assumes that the consumers are concerned about the way that the fish are reared. It is submitted that this aspect will be explore during the pilot phase. However, conclusions from the trial at the Agricultural University of Bangladesh indicate that this may not be a major constraint because the researchers have endorsed the use of BSF larvae as a component of fish feed. Furthermore, most of the consumers of reared fish in Bangladesh are not aware of the things that are being fed to cultured fish. There are aquaculture projects where waste from poultry and ducks are fed directly to fish to supplement their fish feed costs. BSF larvae has much higher nutrition value then poultry and duck waste.

Consumer concerns could be alleviated by explaining to them that insects are part of the natural diet of fish. Therefore, feeding fish with BSF larvae would be consistent with natural order of things. During the pilot, the implementing parties will explore consumer concerns by conducting field research about any issues that they may have regarding the use of BSF larvae as partial fish feed. Researchers in Agricultural University of Bangladesh suggest that this would not be an issue because they have not raised that concern.

9. Critical Success Factors

Trying to partially or completely substitute commercial fish feed with feed produced from BSF larvae is a pioneering project in the context of Bangladesh. In-depth analyses of the myriad aspects of implementing the project suggest that further exploration of this idea is merited. This section will provide details of the critical factors for ensuring the success of the project. There are two broad categories of critical success factors: Business considerations and Technical Considerations.

9.1 Business Considerations

The financial benefits of implementing this project on a commercial scale is one of the key critical success factors for the wide adoption of this technology in Bangladesh. Unless this venture can enable the fish farmers of the BG target areas to reduce their cost, and thus increase their income, the technology will be of limited value for the target farmers. The technology also needs to ensure that the people who are involved in the business, such as the breeders and suppliers of BSF larvae, are able to make a profit; otherwise they would not have an incentive to engage with the business of using BSF larvae to make fish feed.

The primary focus here is to able to extract value from resources, such as organic waste, which have not been properly utilised in Bangladesh and optimise the value generation from the aquaculture industry through the use of higher quality fish feed at competitive prices.

Since there is no comparable industry in Bangladesh, it would be myopic to make unsubstantiated claims because precise projections are difficult to make without reliable data. The fact that a number of companies are actively working in China, Indonesia, etc., to commercialise this technology strongly indicates that the use of BSF larvae to substitute fish feed is an economically viable endeavour.

The pilot phase is crucial for the development of this technology because it will provide valuable concrete data about the inner workings of the technology in Bangladesh, which will help the contracting parties to make more accurate projections and a very well developed strategy to commercialise the technology. The critical business success factors are: initial capital expenditure, access to raw materials, income streams and social acceptability.

9.1.1 Capital Expenditure

Setting up a facility to breed BSF larvae requires some capital investment. Given the fact that the use of BSF larvae as an alternative fish feed is a novel project, the initial cost is a significant impediment for the promulgation of this technology. Financial institutions may be convinced to provide capital resources once they are furnished with reliable data about the projected income and the consistency of the earnings. However, reliable data can only be provided after the completion of the pilot phase.

Additionally, fish farmers would also have to make an initial investment to set up their BSF larvae facility. Since many farmers in the BG target areas do not have access to capital, demonstrated by the fact that they face cash flow constraints even in relation to purchasing the fish feed, it is likely that the contracting parties would face some resistance in relation to the implementation of the technology. However, capital expenses for the rearing facilities for the farmers can be substantially reduced by providing the rearing units to the fish farmer on a fractional payment basis. The contrasting parties can provide the larvae units for free of cost to the fish farmers initially; the farmers could then pay through monthly instalments over a period of time.

Provided strategies are implemented to reduce the barrier to entry in relation to the production of BSF larvae, it is submitted that the target fish farmers would be quite interested to play an active role in the production of BSF larvae because it would offer them significant cost savings.

Addressing this challenge would involve carrying out a pilot project to demonstrate the proof of concept to potential investors, including the BG Innovation team. The pilot would also provide reliable data which can be used as a benchmark to re-calibrate the financial projections that have been made in the report. Finally, conducting the pilot would also facilitate the implementation of the decentralised model for rearing BSF larvae as an alternative fish feed because the breeding facility constructed during the pilot could be renovated, with substantially lower financial resources, so that it can be operated as the key facility for the commercialisation phase. Consequently, a significant portion of the resources of the pilot phase can be re-used for the commercial phase.

It is submitted that the contracting parties may have to cover the cost of setting up the rearing facilities for the fish farmers in the BG target areas during the course of the pilot because the farmers may not be inclined to make any investment in a new technology given their financial constraints. Consequently, the contracting parties would allocate some of the resources of the pilot phase to set up small rearing facilities (up to 5 larvae rearing boxes) for each farmer, as a proof of concept. Provided sufficient funding is available, the contracting parties would want to set up these small rearing facilities in all three locations of the BG target area so that the contracting parties can obtain a large pool of sources for the data.

Large data pools would ensure that the contracting parties obtain representative data, which would allow the contracting parties to make more accurate projections for the commercialisation phase and thus allow them to manage the risks of implementing this technology more effectively.

9.1.2 Income Streams

The success of the decentralised business model is contingent on ensuring that both the BSF breeding facilities and the rearing facilities are able to generate reliable income or benefit in kind for the people who would be involved in the use of BSF larvae as alternative fish feed.

The primary source of income for the breeding facility would be the sale of BSF hatchlings to the farmers who operate the rearing facilities. It may also be possible for the breeding facilities to sell the larvae castings as organic fertilisers; however, there is no data to make an accurate projection about the potential income from selling the larvae castings. The pilot would provide an ideal opportunity to explore this source of income or any other sources.

Farmers who operate the rearing facilities would be able to generate income by selling the BSF larvae to other fish farmers and by selling the larvae casting as organic fertiliser. Alternatively, they could use the larvae for their own fish stock and use the larvae castings for their own agricultural production. If the farmers rear the BSF larvae for their own purposes, the benefit they obtain from using the outputs of the rearing facility may not be apparent to them. However, they may see the advantage of operating the rearing facility once they discover that they have more money in their pockets because of the reduction of costs associated with commercial fish feed and fertilisers.

Another option that will be explored in the pilot is processing the insect larvae for particular fish species. Processing the larvae and selling the final products can offer a significant source of revenue because that stage can add substantial value to the final outputs, namely, larvae based fish feed and organic fertiliser. It is submitted that industrial processing of the final outputs may be more suitable for centralised larvae rearing facilities because that would allow the organisation which operates the centralised facility to benefit from the economies of scale. Capital requirements for establishing a processing and packaging plants could make them financially non-viable for the decentralised model.

9.1.3 Access to Biomass

Organic waste or biomass is an essential requirement to cultivate BSF and its larvae. Mass production of larvae would require continuous supply of detritus. Given that the larvae and the fly do not have specific preference as to the biomass, the breeding and the rearing facilities can use a wide range of organic waste. These could include: manure, house hold waste, human waste, slaughterhouse waste and other organic plant matter that are not used for anything.

In relation to the decentralised model, farmers could use their household waste, waste from their live stock and other organic matter which they throw away at the moment. This means that the cost of collecting the biomass would be much lower for the fish farmers in the target areas. The proposed model would offer the fish farmers a clear incentive to manage their waste because they would be able to substantially benefit form this practice. Additionally, better waste management would reduce contamination of water and land in the vicinity of the fish farmers in the BG target areas because waste materials would not be left exposed.

Access to reliable source of biomass may be an issue for the centralised model for rearing BSF larvae because the centralised facility would require a huge amount of biomass. Furthermore, accumulating biomass from distant locations could significantly increase the operational cost of a centralised facility. It may be more cost effective to set up such a facility near a large source of organic waste, such as land fill, market or slaughterhouse, and then transport the processed fish feed and organic fertilisers to the desired location.

Although centralised BSF rearing facilities would need access to electricity and gas, these facilities have much lower energy requirements than current commercial fish feed factories. This offers a large degree of flexibility in relation to the location of the centralised facilities. They can be located in different regions of Bangladesh, as opposed to current fish feed factories which are concentrated in the industrial belt of Bangladesh near Gazipur and Dhaka-Chittagong Highway.

The pilot phase will provide valuable data as to the precise biomass requirements for decentralised business model. Additionally, it will provide a clear picture of any limitations that may arise in relation to the acquisition of biomass for the breeding and the rearing facility. Finally, the pilot can provide reliable data in relation to the expected biomass requirement for a centralised business model. This will allow the contracting parties to explore the challenges of collecting large amount of biomass and develop detailed strategies to resolve them.

9.1.4 Social Acceptability

At the start of the project, some valid concerns were raised by members of the BG team that the fish farmers may be disinclined to use insect larvae based fish feed because there may be a consumer back lash. The concern arises from the fact that BSF larvae can be reared on a wide range of organic waste, including human excrement. Given the social dynamics of the consumers of Bangladesh, this may be a major impediment for the adoption of this technology.

In order to address this concern, the contracting parties carried out detailed field research where they interviewed the fish farmers in the BG target area to obtain their views on this technology. Data from the interviews strongly indicate that the farmers are quite willing to use fish feed made from BSF larvae, provided that the quality of the feed is comparable to the feed currently available and the product is competitively priced.

It is interesting to note that these farmers have been feeding a variety of things to their fish stock, which include: manure, snails, fermented rice, etc. They did not seem to have any issue with the idea of using of BSF larvae as a substitute for fish feed. However, the pilot phase would provide concrete evidence to corroborate their claims and address any other concerns that these farmers may have with the use of BSF larvae as fish feed.

Some farmers in the BG target areas were quite enthusiastic about the idea, and they have expressed their interest to take part in the pilot. It is submitted that incorporating these farmers would be very helpful for implementing this technology, because it would enable the fish farmers in the BG target areas to actively participate in the development of this technology and have a stake in its success.

9.2 Technical Considerations

So far, the report considered the critical factors to ensure that the success of this technology as a business venture. However, the success of the technology is also contingent on some important technical issues. These issues are quite manageable; however, lack of reliable and relevant data, specially in the context of Bangladesh, means that a cautious and focused approach is advisable. Key issues for the success of this technology involves: climate conditions, processing the feed, infestation by foreign insects, risk of disease and managing odour.

9.2.1 Climate Conditions

Research and data indicates that the climate conditions in the BG target areas are very favourable for the growth and reproduction of BSF. However, given the fact that there has been no attempt to rear BSF commercially in Bangladesh so far, there may be some unexpected issues arising from specific climate conditions in the BG target areas.

To ensure that BSF and its larvae are bred and reared in optimal climate conditions the contracting parties will install monitoring devices in the breeding and the rearing units during the pilot phase to monitor and evaluate the environment. Since large temperature variations can have a negative impact on the reproduction and growth of BSF, the contracting parties will develop procedures to address them. Drops in temperature, specially during winter, can be addressed by covering the larvae rearing pens so that the heat generated by the larvae are retained. The breeding units may also be covered during the night to protect the BSF from the cold. The implementation of a heating system or other alternative would also be considered, if necessary.

Light exposure is critical to encourage BSF to mate and lay their eggs. Detailed observations of the flies in the breeding units will provide valuable information about the optimal method for exposing the BSF to light. Relative humidity of the feed and the air is also important for the growth of larvae and for the eggs to hatch. Therefore, the relative humidity would have to be closely monitored, and appropriate remedial conditions will be implemented, to ensure optimal environmental conditions for the larvae and the eggs.

Precise records of the feed and the insects would also be made, because that would provide more accurate data about biomass requirements, biomass conversion ratio, larvae yield and mass of larvae castings. These records will help the contracting parties to optimise the production process and maximise the outputs.

9.2.2 Feed Composition and management

BSF larvae are voracious consumers of a large variety of organic waste. They are not too picky and they will eat pretty much anything. However, the composition of the biomass directly impacts the nutritional profile and the growth of the BSF larvae. Optimising the growth of the larvae and nutritional profile of the larvae for specific fish species which are reared in the BG target areas would involve rearing the larvae on different organic waste.

During the pilot the contracting parties will explore how the composition of the feed should be manage to optimise the growth of the larvae and its nutritional content, given the constraints faced by the fish farmers who would be rearing the larvae. The objective here would be to determine easily accessible waste material can be used by the fish farmers to optimise the nutritional profile of the larvae for their specific fish stock. In order to manage the data and make comparable conclusions, the pilot may focus on some specific fish species.

Feed management is also important because rodents and other insects could infest feed that is stored for the larvae. Generally, anaerobic bacteria are responsible for bad odours. Aerating the stored may reduce the proliferation of anaerobic bacteria. The most effective way to manage the feed is to ensure that they are consumed by the larvae regularly because that prevents house fly infestations of the bio mass. BSF larvae generally outcompete house fly larvae.

The pilot would develop proper procedure for collecting and handling the biomass to minimise unwanted odour and reduce the risk of infestation by rodents and unwanted insects.

9.2.3 Processing Larvae and Larvae Castings

The primary of objective of this project to is develop a viable alternative to commercially available fish feed. Therefore, it is quite important to explore various options for processing the larvae to determine which method promotes the highest utilisation (feed conversion ratio) by the reared fish.

The processing procedures that will be explored in the larvae include: feeding live larvae to the fish, killing the larvae in hot water (or in an oven) and then chopping them, the optimal time for harvesting the larvae and drying the larvae and grinding them to a powder so that it can be mixed with other types of feed.

Feed requirement for the reared fish depend on the stage of development of the fish and the species of the fish. Therefore, the pilot would provide valuable data about how to process the feed for specific fish at a given stage of their development.

Since the larvae casting can provide an additional source of income for the fish farmers, it is submitted that further investigations of the amount of rest waste is important. Precise indication of the amount of casting generated by the larvae can provide an accurate estimation of the income that can be generated from its use or sale.

9.2.4 Diseases.

Since adult BSF do not eat, they are not considered a vector for diseases. However, no case have reported about diseases that have killed BSF larvae. These larvae are quite robust. If larvae perish or grow too slowly due to microbial infestation, normal procedure is to kill the larvae, thoroughly clean the affected surfaces (e.g. boxes or containers) and restart.

9.3 Conclusion

The success of using BSF larvae as an alternative fish feed is contingent on the critical success factors that have been outlined above. Delineating these factors provides observable benchmarks for the pilot phase. Although this technology has a lot of promise, its successful implementation is contingent on finding workable solutions to the issues raised above. These issues can be resolved; however, successful resolution requires specific data from the BG target areas because that would enable the contracting parties to design a business model that are specific to the requirements of the fish farmers in the BG target area.

10. Preliminary Plan for Pilot

This section will provide a broad outline of implementing the pilot project in the BG target areas. The pilot will involve setting up a breeding facility for rearing the BSF and producing the larvae. The larvae will then be distributed to the participating fish farmers in the BG target area.

10.1 Objectives of the Pilot

Based on the analysis of this study, it is submitted that the pilot project for the development of BSF larvae as fish feed has these objectives:

1. Establish a commercial protocol for the production of BSF larvae in Bangladesh;
2. Collect detailed data about the production of BSF on a commercial basis in BG target areas;
3. Develop evidence based solutions for resolving the critical factors for implementing larvae production facilities (breeding units and rearing units) for the commercial phase; and
4. Re-analyse the optimal business model for commercialising the technology.

It is submitted that the pilot would not be able to raise any revenue, during the commission of the pilot, from selling the larvae hatchlings to the fish farmers in the BG target area because this is a truly innovating approach for resolving a key constraint of the growth of aquaculture. Data from the field research indicates that the target fish farmers are inclined to participate in the project; however, they were abundantly clear that they do not have the resources to invest in a technology which has not been completely adopted for the specific conditions of Bangladesh.

Given these financial constraints, it is submitted that the pilot would involve setting up a breeding facility which will aim to produce about over 500 kg of larvae per cycle. This will enable the contracting parties to raise sufficient eggs to supply the BSF larvae rearing units for about 15 farmers in total (which is about five farmers in each of the BG target areas). Given the early stage of development of the technology of using insect larvae as fish feed, it is suggested that the contracting parties would have to finance the larvae rearing units. This will encourage the farmers to participate in the project, and once they see the benefit of this technology, they may be very excited to set up their own larvae rearing facility.

The facilities of the pilot will be retained because they would be utilised for the commercial phase. The rearing boxes will also be retained for future use. These boxes can be sold to the farmers, or they could be rented out to reduce the capital expenses for the BG farmers to set up the rearing facilities.

It may be possible to market the larvae castings as organic fertilisers, but people may be reluctant to use it at first because this has not been done before in Bangladesh. A better idea would be to give out free samples so that people can see the benefits of organic fertiliser.

10.2 Broad Strategy for Implementing the Pilot

In order to ensure that all the objectives are reached in the pilot, it is essential that the contracting parties have access to skilled labour who would be able to develop, implement and manage the pilots in the most effective manner. Given the fact that BSF, or insects in general, have not been reared on a commercial scale in Bangladesh, the contracting parties think that at least one member of Aspire, the organisation implementing the pilot in Bangladesh, should be properly trained in breeding and managing the entire life cycle of BSF.

The training is essential because breeding BSF can be quite tricky. To ensure that smooth operation of the pilot, it is submitted that the first thing is to ensure availability of skilled labour. Additionally, the qualified member can then help the farmers in the BG target area about breeding the flies, provided that they are interested.

During the training, members of Aspire would finalised the acquisition of a parcel of land one of the BG target areas. The contrasting parties could initially lease land from one of the frames during the pilot phase to mitigate costs. After the training, construction for the breeding installations and the larvae rearing units will be initiated. The contracting parties will also explore the options for sourcing adequate biomass for the pilot, and finalise strategies to obtain the required biomass and establish the protocol for the composition of the biomass.

The pilot programme would involve setting up a larvae breeding facility in one of the BG target areas, which will be operated by Aspire with the support of Insectsforall. The contracting parties, will aim to provide between 5 and 10 larvae rearing units to members of a community of fish farmers in each of the BG target area (Khulna, Patuakhali and Satkhira). Initially, the project will start off with providing the larvae for one region. Within a couple of cycles, the project will roll out the larvae for the remaining regions.

The breeding facility will have three structures: the breeding unit, the rearing unit and biomass storing unit. Protocol will be developed and implemented by trained personnel, so that the weight of the BSF at each stage of the development, the feed composition, weight of feed before and after it is processed by the larvae, the ambient temperature and relative humidity are recorded in an organised manner. These protocols will ensure that data is recorded at regular intervals throughout the course of the pilot.

Assuming that the pilot project starts before the onset of winter in Bangladesh, BSF will also be harvested from the wild during the construction phase because BSF may not be very active during the winter season. The harvested wild flies will be the initial brood for the production of BSF, BSF eggs and BSF larvae for the pilot.

Additionally, most of the fish farmers in the BG target areas take a hiatus from fish farming during winter months because fish are not very active during that time. The lull in aquaculture during the winter months will give the contracting parties the opportunity to initiate the breeding process and complete a few BSF life cycle. This will ensure that there are enough larvae for the fish farmers before the start of spring. During the construction phase, the implementing organisation will make the final selections of the participating fish farmers and work with them to ensure that they are prepared for rearing the BSF larvae.

Once the eggs hatch in the breeding facility, the larvae will be fed on biomass with varying composition to determine how the biomass effects their nutritional profile. The contracting parties will explore the possibility of tying up with a tertiary education institution or a government research institute, such as Khulna University or the Bangladesh Agricultural Research Institute, who would have access to the equipment to analyse the larvae and help the contracting parties to fine tune the composition of the biomass. Research and development is an essential part of this pilot project because there are many variables whose impacts have to be explored and analysed to ensure that the project is commercially viable in the future.

Moreover, these institutions can also help in determining the optimal way of processing the larvae so that the fish are able to effectively utilise the larvae based feed. Determining this is crucial because the ultimate goal of this project is to develop a viable alternative to the commercially available fish feed. If the cultivated fish are unable to utilise the larvae based feed properly, then it would increase the cost of rearing fish.

After the initial phase, the larvae rearing units will be distributed to a community of BG farmers. The reason for incorporating farmers from all three target areas is to ensure that the data from the pilot is derived from wide pool of sources. Larger pools of data source would provide a more accurate and representative reflection of the specific conditions of the BG target areas. It should be noted that this is the ideal proposal for the pilot. After considering the feed back from the BG team it is submitted that the pilot could reduce the number of locations for rearing the BSF larvae but increase the duration of the pilot.

The breeding facility will operate to breed BSF and produce larvae. These larvae will be distributed to the participating farmers for the remaining nine months to replenish their stock of adult larvae because the farmers will be feeding the larvae to their fish stock. Rearing the larvae and feeding them to the fish will be closely monitored by Aspire to ensure that the participating farmers follow the parameters of the protocol. The contacting parties will also moni-

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tor the growth of the fish to determine the feed conversion ratio of the larvae based fish feed by the different types of fish which will be cultivated.

At the conclusion of the pilot, the contracting parties will have detailed data in relation to breeding BSF, rearing BSF larvae and processing the larvae as fish feed. Analysis of the data will provide an insight about the challenges of associated with this technology in Bangladesh, and help the contracting parties to devise targeted strategies to resolve those issues. The data will also help the contracting parties to re-evaluate their strategies for commercialising this technology and develop a strong case for implement the next phase.

10.3 Summary

The pilot project can be broken down into three phases. Plans for each phase are provided in detail below. It is estimated that the duration of the pilot will be one year and six months to two years (as suggested by the BG members during the presentation).

10.3.1 Phase One

This phase will take about four to five months. During this period the following issues will be resolved:

1. Obtaining access to land through a medium term lease from farmers,
2. Construction of cost effective breeding units for BSF and boxes for rearing BSF larvae (because it may not be financially practical to construct three permanent concrete units during the pilot),
3. Training of skilled staff,
4. Contact tertiary education institution and government research institutes,
5. Developing management and data collection protocols,
6. Harvesting wild BSF,
7. Sourcing sufficient biomass for the breeding facility,
8. Completing a number of BSF life cycles,
9. Accumulate sufficient larvae for phase 2,
10. Obtaining the larvae rearing units,

11.Selecting the participating farmers,

12.Training selected farmers to rear the BSF larvae, and

13. Help farmers source biomass for their rearing units.

10.3.2 Phase Two

This phase will take about ten to twelve months, the primary object of this period is to collect data and try to optimise the entire value chain. Key objectives of this phase are as follows:

1. Collect and analyse the biomass composition (visual and laboratory analyses),
2. Research and development in relation to optimising breeding techniques of BSF,
3. Organise and execute a site visitation by Insectsforall, the purpose of which is to validate the business case, check the implementation of breeding and rearing protocols, try to obtain answers on the questions arising from the pilot, meet the farmers participating in the trials and record their experience for analysis and adoption,
4. Monitor the rearing process of the fish farmers in the BG target area,
5. Ensure that data collection procedure is correctly implemented,
6. Collect and organise data from the rearing facilities and the breeding facilities,
7. Observe the utilisation of the larvae based fish feed by the cultivated fish,
8. Explore various processing procedures of larvae as fish feed to optimise their utilisation,
9. Work with the education and research institutes to analyse the nutritional profile of the larvae,
10. Resolve challenges arising from larvae scale production of BSF and rearing them, and
11. Explore various options of income generation by the breeders and the fish farmers,

10.3.2 Phase Three

The final phase would be around three or four months. This phase will be initiated during the end of phase two to optimise the pilot phase. The primary focus of this phase is to analyse the collected data and develop a plan for the commercialisation phase based on concrete evidence. The objectives of this phase include:

1. Analyse the proposed business models based on the collected data,
2. Assess plans for expanding the breeding facility for the commercial phase,
3. Re-evaluate the costs of operating commercial rearing facility by farmers,
4. Develop strategies to manage the issues related to the critical success factors of developing this technology in Bangladesh, and
5. Complete report for the pilot phase.

Thought out the pilot phase the contracting parties will provide regular updates about the status of the project to ensure that the BG programme is informed about the progress of the pilot.

11. Business Case for Pilot

The business case for the pilot provides the CAPEX and OPEX for setting up the pilot within a decentralised business model for developing this technology. The scale of the pilot is much smaller, which means that the earnings and the expenses are reduced. In order to make a projections, the following assumptions are made.

11.1. Assumptions for Pilot

The assumptions have made these on the basis of literature and field research to ensure that they are representative of the market conditions in the BG target areas. These assumptions are also modified form the ones provided above at section 7.1. Assumptions for the projected investment costs and projected income in relation to the pilot are provided below.

11.1.1 Assumptions for CAPEX and OPEX for the Pilot

1. Cost of constructing the various units are much lower because the pilot would involve smaller installations on land rented from local farmers.
2. One small scale breeding and one small scale processing unit will be set up for the pilot.
3. Breeding unit will have cages of volume 1 m^3 and each cage will be able to house 3000 flies. There will be about 10 cages initially for the pilot.
4. The breeding facility for the pilot will use about 15 tons of biomass per year for initial exploration of the commercial viability of the technology
5. Each rearing facility for the pilot would probably need one structure to house the boxes because they would be operating only five boxes. This will substantially reduce the cost of setting up and maintaining a rearing facility during the pilot.
6. Fish farmers in the BG target area are able to replace up to 75% of their commercial fish feed with BSF larvae.
7. The pilot rearing facility has a theoretical capacity of 375 kg of of dry fish feed per year and 5.5 tons of larvae castings per year, based on the fact that the farmers would be operating 5 large boxes and mass balance calculations.

8. Measuring and handling devices include thermometers, shovels, carts, humidity meters, weighing scales (large and small), fans, tarpaulins for covering breeding units to reduce heat loss at night, etc.

9. Given the biomass conversion rate of 15% by the BSF larvae, it is estimated that the each pilot rearing facility would need about 11-12 tons of biomass every year to operate.

10. Staff costs for the breeding facilities are higher because operating that facility requires skilled labour such as managers, experts and technicians.

11. Staff costs for the pilot rearing facilities are much lower because the farmers have to manage limited numbers of larvae boxes and it is assumed that the farmers will be rearing the larvae by themselves. The staff cost for the pilot rearing facilities reflects a token amount.

12. Disposable costs include the cost of consumables, such as gloves for handling the larvae, gas for heating water, spoilage, etc.

13. Capital depreciation is excluded from OPEX because it has no effect on the cash flow.

11.1.2 Assumptions for Earnings

1. 50,000 young larvae is considered to be one unit because that is the amount of larvae that can be grown in an 1m X 1m box;

2. Estimated price of one box of larvae is 140 BDT;

3. The price of larvae casting are estimated to be 5 BDT/kg (For details see section 7.1.2);

4. The pilot breeding facility will be able to supply larvae for about 15-20 pilot rearing facility (which is equal to producing 75 units of larvae boxes per month);

5. The estimated benefit that the fish farmers can obtain from BSF larvae based fish feed would be 90 BDT per kg. (For details see section 7.1.2)

6. The yield of the dry larvae are taken from the mass balance calculations (75 kg of dry larvae per cycle would lead to the production of 375 kg of dry fish feed per year by a rearing facility which has 5 larvae rearing units); and

7. Yield of the larvae castings for the pilot are taken from the research trials which indicate that about 50% of the biomass can be harvested as larvae castings.

11.2 Projected income during the Pilot

The pilot will test out the decentralised model for implementing the technology of producing fish feed from BSF larvae. Therefore, there will be a segregation of the chain of production into two parts. One part will be focused on the production of larvae and the other part will be focused on rearing the larvae.

Larvae production will be carried out in the pilot breeding facilities which will then be sold to the larvae rearers in the BG target area. Therefore, the primary source of the income for the breeding facility will be the sale of the young larvae.

Sale of the larvae castings can offer a valuable source of income for the breeding and the rearing facilities. It should be noted that there is no comparable price of the larvae castings at the moment. An accurate indication of the price would be obtained during the pilot.

The chart below demonstrates that expected earnings for a breeding facility that would be able to supply young larvae to 15-20 small rearing facilities with (up to) 5 rearing units.

Projected Income: Pilot Breeding Facility

Items	Earnings (BDT)	Earnings (EUR)	Notes
Every Month			
Sale of young larvae	13,125	138	See section 11.1.1
Sale of larvae castings	3,000	32	See section 11.1.1
Subtotal (Monthly)	16,125	170	
ANNUAL TOTAL	193,500	2,037	

Fig. 6.1 Projected Income for Pilot Breeding Facility

The next chart provides the income (i.e. cost savings from substituting commercial fish feed and income from sale of larvae castings) that the farmers who participate in rearing BSF larvae during the pilot phase. The pilot rearing facilities are estimated to produce 375 kg of dry larvae annually and 5.6 tons of larvae castings.

Projected Income: Pilot Rearing Facility

Items	Earnings (BDT)	Earnings (EUR)	Notes
One Box of Larvae per production cycle			
Benefit from substitution of commercial fish feed	450	5	For details, see 11.1.2
Earnings from larvae casting as organic fertiliser	375	4	See section 11.1.2
	Earnings (BDT)	**Earnings (EUR)**	**Notes**
5 Boxes of larvae per Annum (15 cycles)			
Benefit from substitution of commercial fish feed	33,750	355	See section 11.1.2
Earnings from larvae casting as organic fertiliser	28,125	296	(As above)
AUNNUAL TOTAL	61,875	651	

Fig. 6.2 Projected Income for Pilot Rearing Facility

11.3 Projected Costs

The pilot would requires some initial capital investment because breeding and rearing the BSF and its larvae requires the construction of facilities. Given the exploratory nature of the pilot, the contracting parties have tried to keep the initial capital expenditure and the operational expenditure as low as possible.

Segregation of the chain of production mens that, in theory, the fish farmers in the BG target area do not have to bear the cost of the rearing and the contracting parties do not have to bear the cost of the rearing units. However, it would be impractical to expect the fish farmers to make any investment at the pilot phase given their financial constraints. The fish farmers would, nevertheless, be encouraged to contribute to the operational expenses (OPEX) of the rearing facilities, because that would give them a stake in the project and thus ensure that the farmers work with the implementing parties to make this project a success.

The charts below set out the capital expenditure (CAPEX) and OPEX for both the rearing facility and the breeding facility.

Projected Capital Expenditure: Pilot Breeding Facility

	Costs (BDT)	Costs (Euro)	Notes
CAPEX-PB (Breeding Facility)			
Breeding Unit	120,000	1,263	For details see section 11.1.1
Biomass Storage Unit	20,000	211	(As above)
Wooden Cages	25,000	263	(As above)
Technical Training	300,000	3,158	
Electrical equipments	50,000	526	(As above)
Measuring and Handling Devices	50,000	526	(As above)
Administrative licences	10,000	105	
TOTAL	**575,000**	**6,053**	

Fig. 6.3 Projected Capital Expenditure for Pilot Breeding Facility

Projected Capital Expenditure: Pilot Rearing Facility

CAPEX-PR (Rearing Facility)			
	Costs (BDT)	**Costs (Euro)**	**Notes**
Larvae growing boxes	27,500	289	If the boxes can be reused for the commercial phase
Rearing Unit	15,000	158	
TOTAL	**42,500**	**447**	

Fig. 6.4 Projected Capital Expenditure for Pilot Rearing Facility

Projected Operational Expenditure: Pilot Breeding Facility

OPEX-PB			
Costs per month	**Costs (BDT)**	**Costs (Euro)**	**Notes**
Staff	60,000	632	See section 7.1.1 for details
Disposable costs (gloves, gas, spoilage)	3,000	32	
Electricity and Water	1,000	11	
Research and Development	10,000	105	
Administration	1,000	11	
Substrate (Biomass)	2,000	21	
Contingency	1,000	11	
Sub Total	78,000	821	
ANNUAL OPEX-PB	**936,000**	**9,853**	

Fig. 6.5 Projected Operational Expenditure for Pilot Breeding Facility

Projected Operational Expenditure: Pilot Rearing Facility

OPEX-PR			
Costs per month	**Costs (BDT)**	**Costs (Euro)**	**Notes**
Staff	1,000	11	See section 7.1.1 for details
Substrate (Biomass)	500	5	
Cost of young larvae	875	9	One month is equal to 1.25 cycles (approx)
Disposable costs (gloves, gas, spoilage)	500	5	
Contingency	500	5	
Sub Total	3,375	36	
ANNUAL OPEX-PR	**40,500**	**426**	

Fig. 6.6 Projected Operational Expenditure for Pilot Rearing Facility

11.4 Cost Benefit Analysis

This section provides the profit analysis for the pilot phase for developing BSF larvae as a substitute (partially and completely) for fish feed. Deducting the projected operational costs from the projected operational income, illustrates the profit that can be expected from operating the pilot phase. Given that the objective of the pilot breeding facility is to obtain data and establish commercial protocols for commercialising the technology, no profits are expected directly from the operation of the pilot breeding facility. However, the rearing facility does provide a profit.

It should be noted that these small scale pilots are not representative of the true potential of commercialising the project because when the breeding facilities and the rearing facilities are scaled up, they will be able to benefit from economies of scale. Even though the CAPEX and OPEX for the commercial phase would be higher than for the pilot phase, the breeders and the rearers (BG fish farmers) of BSF larvae, the income becomes higher. Thus, the net profit for the participants in the commercial phase would be much higher.

Based on the expected profit, the section then demonstrates the expected time for recuperating the initial capital investments.

Expected Profit from Pilot Rearing Facility

Per Annum	(BDT)	(Euro)	Notes
Expected Earnings	61,875	651	See fig 6.2
(Less) Projected OPEX-PR	40,500	426	See fig 6.6
Net PROFIT	21,375	225	

Fig 6.8 Expected Profit (Pilot Rearing Facility)

Based on these expected profits it is estimated the return on investments for the breeding facility and the rearing facility are given below. Return on investment is defined as profit divided by capital expenditure multiplied by 100%

Return on Investments

Rearing Facility			
Return on investment (%)	PROFIT from Rearing facility / CAPEX-PR	50	See fig 6.8 and fig 6.4

Fig 6.9 Return on Investment

The numbers indicate that the fish farmers in the BG target area should be able to recover their capital investment within two years, if the fish farmers invest in the rearing facilities. If, however, the BG farmers do not invest and the contracting parties finance the rearing facilities, then the BG farmers would stand to gain much more. It is submitted that for the pilot phase, it would be prudent for the contracting parties to finance the rearing facilities but request the BG farmers to cover the operational cost.

There would be no profit for the pilot breeding facility because it is intended to operate as a research facility. In fact, the pilot breeding facility would be operating at a loss. However, it is submitted that the marginal cost of producing additional units are much lower. Therefore, the breeding facility would become profitable when it is scaled up. When the breeding facility would be operating to produce about 1250 larvae boxes per month, it would be producing sufficient revenue to cover its operational cost and make a profit. At the commercial scale, the breeding facility would recover its cost of capital investment within three years.

Based on these analyses, it is submitted that further exploration of this technology is merited because it can offer the fish farmers of the BG target area a great opportunity to increase their income and reduce their costs of rearing fish.

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12. Conclusions

This report has provided a comprehensive analysis of the technical, climatic, economical, social and legal analysis of the myriad issues involved with the development of BSF larvae as an alternative source of fish feed in Bangladesh. It has provided a through analysis of the market conditions related to aquaculture in the areas where BG operates.

Given the challenges faced by the fish farmers of Bangladesh, particularly, the fish farmers in the BG target area, it is submitted that innovative solutions have to be devised to enable the farmers (especially, poor farmers) to overcome their limitations in the aquaculture industry in Bangladesh and expand their businesses. Traditional methods of cultivating fish stock is not sustainable for many farmers in Bangladesh because it requires regular injection of capital to purchase commercial feed and feed the fish. These capital constraints have a negative impact on the final yield of fish, meaning that the farmers are not able to maximise their return from fish cultivation.

This technology has the potential to make aquaculture much more accessible, because it would reduce the barrier of entering into the aquaculture industry.

Increased participation by fish farmers and non-fish farmers in the BG target areas, will have a major impact on the living conditions of the people of that region because aquaculture has helped many people break free from poverty. Although, many people in the BG target area raise fish for their personal consumption, it is quite possible that these people would be interested in commercial cultivation if they discover that they can make a substantial gain.

The report has also provided detailed guidelines about the most effective way to breed and rear the BSF larvae for consumption by fish. However, there should be no illusion about the challenges facing the implementation of this technology in Bangladesh. Many issues have yet to be resolved, but those issues will only arise when the contracting parties with the support of BG programme implement the Pilot.

Data indicates that there is great potential for this technology. Therefore, it is recommended that the pilot phase is implemented.

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https://www.youtube.com/watch?v=dhQ1iTFRj7Y (Video of an operational low cost BSF larvae rearing and production facility in Ghana)

https://www.youtube.com/watch?v=ZbSYk-H2m4w&t=140s (Video of a BSF production facility in China)

Appendix A

Feedback from Presentation

Once the draft report was submitted, the contracting parties provided a presentation based on the findings of the research and analysis. Overall there was a positive response to the findings of the report, however some concern were raised. This section provides an overview of the issues that were raised and responses to them.

1. The report did not provide references to the research that was conducted in Bangladesh.

The parties have rectified this situation. At section 4.3.1 the report refers to the research trial that was conducted in Agricultural University Bangladesh. The research clearly demonstrates that BSF larvae has been successfully reared in an artificial setting in Bangladesh. The researchers also conclude that there is a great potential for the use of BSF larvae as a partial substitute for fish feed.

2. Legal issues relating to artificial rearing of BSF larvae as fish feed.

Although the Fish Feed Act does not explicitly exclude the use of BSF larvae as a component of fish feed, members of the Blue Gold team were concerned about this. It has been accepted that further consultation with the Department of Fisheries would be carried out before and during the pilot phase to ensure that the rearing of BSF larvae is consistent with the policies of the Department of Fisheries of Bangladesh. It should be noted that the Department of Fisheries is aware of the benefits of the use of BSF larvae as a component of fish feed, because they helped conduct the academic research at the Agricultural University of Bangladesh.

3. Social aspects in relation to the rearing of BSF larvae

There were concerns that people may be less inclined to purchase fish that has been reared on BSF larvae. Data from the farmers of BG target area indicate that they would not have any problems with the sale of fish reared on BSF larvae. Additionally, researchers from the Agricultural University of Bangladesh did not raise this concern in their trial. It is submitted that as a component of fish feed, the use of BSF larvae would not raise major concerns. However, further analysis will be conducted during the pilot phase to ensure that consumer concerns are addressed. It should be noted that farmers already feed duck and poultry waste directly to fish. If consumers have no issues eating fish reared on such inputs, then it would indicate that they may be open to consuming fish reared on BSF larvae when they realise that insects are part of the natural diet of fish.

4. Environmental concerns were raised in relation rearing BSF larvae

Since the project will use native species of BSF, there is no risk of contaminating the environment with foreign insects. The key environmental concern for the use of BSF larvae as feed arises from the production of large volume of larvae, because there would be a risk that the flies might escape and cause problems. Since adult BSF larvae do not eat, they are not vectors for diseases. Furthermore, adult flies would be present only in the breeding facilities which would be under the supervision of the implementing firms. So, it would be feasible to contain them.

The farmers should not have any problems because the larvae, although they are mobile, cannot spread too far. The design of the rearing boxes will provide an adequate solution for the farmers to contain their larvae.

It should be noted that the researchers in the Agricultural University of Bangladesh did not raise any concerns about the environmental aspects. They were of the opinion that the use of BSF larvae to partially substitute fish feed can offer many benefits, including the reduction of organic waste because these waste would be recycled in a sustainable manner to produce a valuable output.

5. Community level interaction

During the presentation, it was recommended that the pilot should be implemented at the community level. It is submitted that this approach will be implemented during the pilot. This would involve the creation of a community which will have a few fish farmers who are interested in participating in the pilot. These people would be given detail instructions and help in relation to managing their larvae. Setting up the community will help the implementation of the pilot because it enable the implanting parties to manage the project more effectively and ensure that the pilot is successful.

6. Concerns about the objective of the pilot

Concerns were raised at the presentation and an email by the BG member that the use of BSF larvae in fish feed is in a very early stage and that the project is not suitable for the BG Innovation Fund because the idea has not been tested in Bangladesh and that there is no protocol for the artificial rearing of BSF in Bangladesh.

These are valid concerns; however, it is submitted that the research section indicates that the concept has been tested in Bangladesh by the Agricultural University. Therefore, there is sufficient evidence to support the view that the BSF larvae can be artificially reared in Bangladesh and the climatic conditions are optimal for rearing BSF large here. There is no data about the industrial protocol for the rearing of BSF larvae, because no one has tried to commercialise the idea.

The objective of the pilot is to provide a proof of concept for the commercialisation of this technology by devising a method to ensure that farmers can rear BSF larvae in sufficient quantities so that they can substitute unto 50 percent of their fish feed requirements. It is submitted that the development of these processes is part of the commercial research because these data will assist the implementing organisations to scale up the project and implement it in all the different regions of the BG target areas.

The issues relating to the legislation, social concerns, environmental concerns are related to the industrial application of the idea. The academic research in Bangladesh has established that the idea is viable here. The objective of the pilot project would be to address the commercial challenges to ensure that the use of BSF larvae as a component of fish feed can be implemented in Bangladesh.

7. Duration of the pilot

Initially, the contracting parties had planned that the duration of the pilot should be 1.5 years. However, member of the BG team have indicated that they believe it would be better for the project to ensure that it is carried out over two years.

Based on their findings, the plan for the pilot have been amended. Currently, the pilot has been projected to last between 1.5 years to two years. This is in line with the suggestions of the BG team.

Conclusion

The members of the BG team have taken a great deal of time to share their views and insights about the project. These insights and views were very welcome and helpful. There are many issues that have been raised and they are valid concerns. However, these issues can only be addressed in the pilot phase.

It should be noted that the members of the BG team where in favour of moving on to the next phase, in spite of these issues. It is submitted that the concerns and challenges that have been raised by the members of the BG team will be taken into consideration when the proposal for the pilot is submitted and during the implementation of the pilot. Currently, the contracting parties are in consultation with the representative of the Department of Fisheries to ensure that the pilot is implemented in accordance with the policies and objectives of the Department of Fisheries.