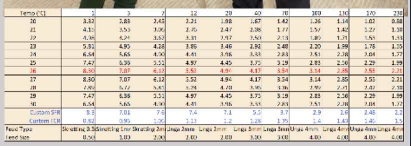

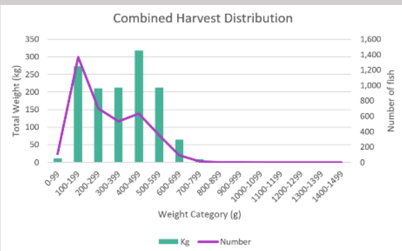

Production strategies for tilapia farmers using small cages in Lake Victoria and similar waters

A Manual with accompanying spreadsheet tool

Version 1.1, February 2024

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The authors are grateful for the support of Victory Farms for hosting and facilitating the research on which this manual is based. To the Unga Group and Skretting for information and guidance on feeds, and to Innovate UK for project funding.

Warning:

NB This spreadsheet is intended as an education and training tool and has not been validated for commercial use. The "predictions" produced by the model should not be relied upon as they are based on limited data and simplified arithmetic calculations. The model can only support planning and decision making when used alongside a good understanding of fish biology, husbandry and farm management. It is particularly important to note that fish growth and survival is highly dependent on local site conditions and suitability, as well as on equipment, feed and seed quality, and the knowledge and skills of the farmer. For users in Kenya, please consult this website for further information about site suitability: http://sawa.blue

Further Information:

Any updates to this manual and spreadsheet, together with video tutorials will be posted at:

www.susaquastirling.net/smalltilapia

Preface

This manual and spreadsheet model is one outcome of a wide range of research around sustainable aquaculture and its contribution to human nutrition and health carried out by staff and graduate students of the Institute of Aquaculture at the University of Stirling, together with many collaborators from other organisations in Europe, Asia, Africa and the Americas. Specifically, it explores the potential for producing and marketing smaller tilapia than conventionally considered optimum for aquaculture. Most likely as a form of diversification of products.

Aquaculture producers have naturally tended to focus on products that have the highest market value and best profit margin. In the context of tilapia farming in Africa, this has generally been medium to larger-sized fish sold to more affluent urban consumers. However, there are wider potential benefits to producing smaller fish. From a societal perspective, these are likely to be more affordable to lower-income consumers including those in more rural locations. A greater percentage of smaller fish tends to be consumed leading to less waste and better nutritional (and therefore health) outcomes. For producers, smaller fish means shorter production cycles which reduces the risk of major losses and the need for working capital. It may also open possibilities for farming mixed-sex tilapia, which could help increase the supply of cheaper fry. It could also unlock local markets which are easier and cheaper to access.

However, there are clear economic drivers for producing larger fish. A 50g tilapia may put on around 1 g of weight per day. However, by the time it is 500g, it may be increasing in weight by up to 5g per day. In other words, individual fish become more productive in biomass terms as they grow larger (at least to a point). Harvesting fish at a smaller size means foregoing improved growth potential. Producing the same harvest weight of smaller fish also requires more fish in total, and the cost of fry is a very significant expense for farmers. Finally, the market price of smaller fish per kilogram is usually lower than the market price of larger fish, so the scope for profitability is further constrained.

The authors have therefore conducted a range of research in both Africa and Asia to explore these drivers in more detail. In particular, they have worked in Kenya with Victory Farms running production trials and market surveys. These helped to confirm some of the advantages of small fish production. This manual and spreadsheet tool is a further step in these activities. We hope it will help producers to evaluate the options based on their production systems and costs and encourage further experimentation and sharing of experience.

The manual and spreadsheet tools were primarily developed as educational materials. No commercial advice is being offered and no guarantee is given as to the reliability of the spreadsheet data and calculations. However, it is hoped that farmers and other practitioners will engage with the materials and use them to consider a wider range of production options – some of which they may wish to explore through at least small-scale trials.

Table of Contents

Introduction

Cage-based tilapia farming in the great lakes has mostly developed over the past twenty years, led by companies such as Lake Harvest (Lake Kariba, Zimbabwe), Tropo Farms (Lake Volta, Ghana), Maldeco Fisheries (Lake Malawi, Malawi), Yalelo (Lake Kariba, Zambia and Lake Victoria, Uganda) and Victory Farms (Lake Victoria, Kenya). However, there are many smaller companies and smallholders and developments in many other African freshwater bodies[1]. There were 3,696 cages in the Kenyan waters of Lake Victoria in 2021, generating sales of KSH 955.4 million (US$ 9.6 million) and employing 500 people with indirect income opportunities estimated for a further 4000 people throughout the value chain[2]. These value chains include 18 fish feed manufacturers and 87 authenticated hatcheries[3]. Substantial opportunities for growth are identified by investment funds such as AquaSpark[4] and Gatsby Africa[5]. However, this will undoubtedly be constrained by social and environmental issues as have been experienced in other locations[6].


Figure 1: Steel frame cages in Kenya

As the sector develops it is likely to become more competitive and only the better-managed operations with good sites and perhaps some scale economies might be expected to remain profitable. Market diversification (both in terms of products and customers) will also become more important.

The purpose of the spreadsheet tool and this accompanying manual is to help smaller-scale cage-based tilapia farmers to better understand the drivers of profitability and to explore different production strategies, especially the production of smaller fish which can more easily be sold to rural consumers, which may also reduce working capital requirements and overall commercial risk.

The first part of the manual covers some important aspects of farming tilapia in cages in tropical lakes, whilst the second part deals more specifically with how to use the spreadsheet model. The manual is not intended to be a detailed or exhaustive guide to farming tilapia. There are many excellent resources on different aspects already available, some of which are listed in the further reading section at the end of the manual (if not already referenced in the text). The material selected for the first part of the manual is therefore limited to discussing some of the key management aspects which are included in the spreadsheet model.

[1] Musinguzi et. al. 2019
[2] Orina et al., 2021
[3] Munguti et. al. 2021
[4] Van der Pijl et. al. 2021
[5] Gatsby Africa, 2018
[6] Eg. Njiru et. al. 2018 & Asmah et. al. 2016

The business of aquaculture

Introduction

Aquaculture, the farming of plants and animals in aquatic environments, has many parallels and indeed, interactions with broader agriculture and livestock rearing. It can be conducted as a subsistence activity, as a small or medium-scale business, or as a corporate enterprise. The focus of this manual is on tilapia farming in cages, conducted as a small to medium-scale business activity. As such, it involves private investment and the expectation of financial profit.

As with other types of farming, the production of tilapia in cages is subject to a wide range of risks, so the potential financial returns on any investment need to be sufficient to encourage the business owners and other investors to take on the risks involved. A good understanding of the risks and how to minimise them whilst also maximising profits is therefore essential for successful businesses. We hope that this manual and spreadsheet tool will help cage-based tilapia farmers to do that.

It is also recognised that business models and business culture can vary both geographically and with time, so what might be well-established “Western” principles may not be quite so applicable in Sub-Sahara Africa, or indeed for the Global North, as new challenges for humankind emerge. Whilst businesses are still mainly designed around maximising returns to investors, there has been growing recognition that businesses are not just economic actors, but can have deep interactions with wider social and environmental conditions. This has led to many businesses giving some weight at least to the interests of other stakeholders including staff, the communities in which they operate, and the environmental resources and services they are using (e.g. the uptake of ESG – Environmental, Social and Governance reporting). Consideration of the broader role that aquaculture producers play in meeting societal needs underpins the work that is reflected in this manual but is not the specific focus. Rather the spreadsheet can be used to consider the financial costs and benefits of strategies that may be preferable from a social or environmental perspective enabling users to reach personal conclusions about the path that is finally taken.

Cage based aquaculture

Cage-based fish farming has mostly developed over the last 50 years. Most systems involve a floating platform or collar from which a net bag is suspended to contain a stock of fish. The cage is usually located in a common water body such as the sea or a large freshwater lake. It is the latter which are the focus of this manual. There are three key attractions of this approach for business investors. Firstly the set-up costs are generally much lower than for a similar production capacity using ponds, or especially tanks on land. The comparison to some extent depends on the ownership of the land or water area and rents that may apply. However, water areas will generally be cheaper as there are few competing uses to drive up rents. Secondly, cages are readily scalable, the number can be increased, or the cage area or depth of the nets. This can have economy of scale benefits and allow for the growth of the business which might otherwise be constrained by available land area or water supply. Thirdly, the cost of maintaining suitable environmental conditions is much lower than in pond and tank systems as there is little to no need for pumping freshwater, adding oxygen, or installing waste treatment systems.

The major disadvantages of cage-based fish farming are mostly linked to the third advantage. The free exchange of water from the water body into the cages provides a route for pathogens which combined with many fish being held near each other means that disease can develop and spread more rapidly. The risks of this increase as the number of farms in a single location increases. Cage-based farms are also subject to other environmental problems such as algae blooms, which can result in fish kills when the bloom dies. Although the wastes from fish feeding are readily flushed from the cages themselves, they can accumulate in the environment, changing it and reducing biodiversity. The accumulation of solid waste beneath cages can lead to localised poor water quality which can affect the fish in some circumstances.

Taking advantage of cage-farm benefits means also taking account of, and mitigating the limitations and risks.

Business models

The purpose of developing a spreadsheet model of a cage-based tilapia farming operation is to help better understand the relationship between different factors affecting production and financial performance. It is necessarily a considerable simplification of reality, but once it is found to provide a reasonable simulation of reality, it can be used to explore the impact of changing different variables to find the limits of business viability. The design of the model depends to a great extent on the questions that it is intended to answer. In the case of this spreadsheet, it is to consider the impact of different stocking and harvesting patterns and the resulting sizes of fish produced on business income and expenditure.

As farming is essentially a biological activity, the heart of the model is a simulation of fish growth; which is dependent on feed input and the efficiency of conversion into fish biomass (feed conversion ratio). This can be affected by various environmental and management factors, very few of which are included in the model. The main examples are water temperature and some allowance for the effect of higher stock densities. On the financial side, the major income is from the sale of the fish, so account is taken of the quantities and sizes of fish produced. The main operational expenditure is on feed and fry used to stock the cages[7]. These are both variable costs which are directly related to production volumes. A very simple indicator is then the margin between income from sales and expenditure on feed and fry. However, to give a broader assessment it is useful to also take account of other significant operating costs, e.g. labour and fuel, and the cost of capital (cages, boats, vehicles) needed to support the production.

A complete financial model would generate projected accounts (particularly a trading, profit and loss account and a balance sheet) whilst an investment appraisal would use projected discounted cash flows to calculate return on investment over a specified period (e.g. Net Present Value and Internal Rate of Return). The model presented in this manual uses a simplified approach taken from management accounting methods for assessing the cost of production and margin analysis. Most importantly it does not take into account the time value of money, so should not be considered a replacement for investment analysis. The purpose is primarily to give a financial metric for the comparison of different biological production strategies. It is essentially a trading, profit and loss account, but with the exclusion of changes in stock value and inclusion of annual depreciation to represent the capital employed. This will lead to a lower profit margin that would be calculated when excluding consideration of capital but will help differentiate strategies that use more expensive equipment.

[7] Obiero et al, 2022

Setting up a cage-based tilapia farm

Setting up a cage-based tilapia farm requires more research and knowledge than can be included here. As mentioned in the introduction, the text here is offered as a supplement to many already excellent resources, and more specifically, as an introduction to the variables that you can adjust in the spreadsheet model, and why they are important.

Figure 2: Small cages in Uganda

Site conditions

The spreadsheet model is intended to model production in tropical lakes where there are relatively minor changes in temperature over the year and the average temperature can be used for growth modelling. The chart below shows average morning and evening temperatures at one location in Lake Victoria and it can be seen that the average diurnal variation is only around one degree Celsius and the seasonal variation is generally within two degrees.

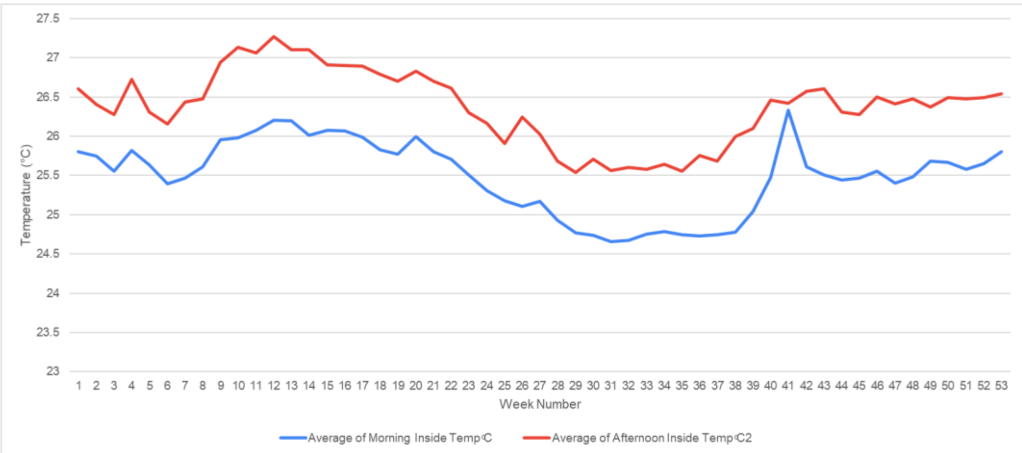


Figure 3: Example morning and afternoon temperatures throughout the year (farm data)

These are average values, so actual temperatures will vary considerably more which will affect farm management on a day-to-day basis. Variations may be due to local effects such as shallow water warming during the day, or wind-induced currents bringing cooler water from deeper waters. In general, temperatures decline with depth, often with a rapid transition at a specific depth (see diagram below). This is a thermocline where warmer water overlays cooler water. This tends to become established during hot stable weather but can be disrupted by a change in seasons and wind patterns. Occasionally such mixing can bring poorly oxygenated water to the surface and cause fish kills. Regular monitoring of temperatures at all depths is therefore recommended to understand risks of this type.

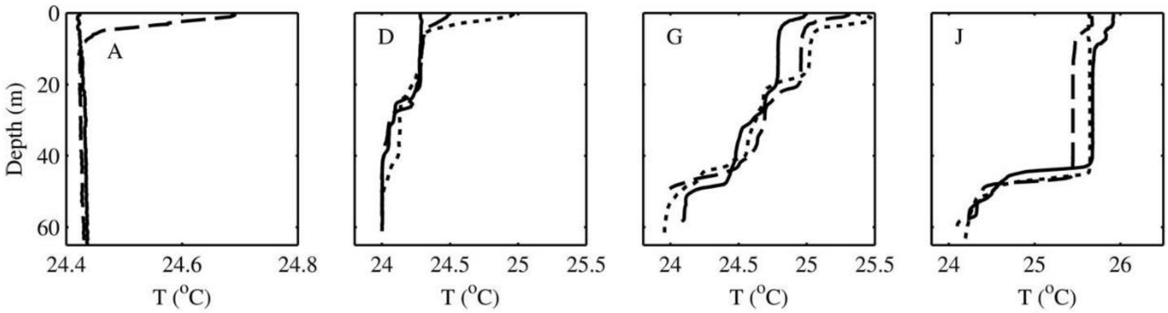


Figure 4: Example plots of temperature against depth showing some of the patterns that can exist (Source: MacIntyre et. al. 2014)

The model, therefore, assumes that temperature and other water quality parameters, particularly oxygen concentration, are within normal conditions for large tropical lakes, with little variation. If there are periods when this might not be the case, e.g. during microalgae blooms and subsequent crashes or significant periods of cooler or warmer temperatures, it would be advisable to model such periods separately.

Licenses, permits and leases

As cage-based aquaculture has developed, so has the complexity of national and local government regulations, and hence the requirement for licences and permits. Full information on requirements here can be difficult to obtain, but the starting point will be the relevant government extension service responsible for aquaculture. In Kenya, these are managed at a County level where fisheries departments will also have a role in managing some of the licencing processes. It is recommended that potential farmers draw up a table similar to the following example to collate the needed information including costs.

Table 1: Identification of regulatory requirements and costs

Issue	Agencies involved (example)	Type of permission	One-off fee (startup)	Annual cost
Permission to operate an aquaculture business	State Department for Fisheries & Aquaculture; County-level Fisheries Department	Permit to operate		
Environmental permission to operate	National Environment Management Authority – Require Environmental Impact Assessment. Other involved agencies involve Kenya Wildlife Services	Site licence		
Consent to discharge into public waters	Water Resource Authority	Discharge consent		
Consent to abstract water from public water sources (if needed)	Water Resource Authority	Abstraction consent		
Site lease – permission to occupy land/water area	National Lands Commission	License/ Lease?		

Issue	Agencies involved (example)	Type of permission	One-off fee (startup)	Annual cost
Boat registration and safety	Kenya Maritime Authority; County authority?	Boat & safety license		
Beach access including fish landings	County/local Beach Management Unit	Approval		
		Totals		

In addition to the main regulatory agencies, there may be other organisations that need to be consulted as part of the process for either the Environmental Impact Assessment or licensing of the activity.

For the spreadsheet, any annual costs are considered a fixed operating cost and are aggregated under the heading "lease". This would also include any annual costs for environmental modelling required by the authorities. The one-off costs for setting up a new site are classed as "Setup costs" and are aggregated under the heading "Survey/Reg/Licenses".

Cage types and sizes

Most cages in use are based around a floating collar from which a net bag (usually nylon or polythene) is suspended to contain the fish. Weights are attached to the net to maintain its shape underwater. The structure is then anchored to the lakebed using metal drag anchors or concrete block anchors connected with ropes. Small cage collars are commonly constructed in wood or steel (preferably galvanised) with polystyrene or plastic floats. Larger cages are now frequently constructed with high-density polythene pipe. These may contain polystyrene for safety in case the pipe is punctured whilst in use.

Figure 5: Mild steel rectangular cages

Figure 6: HDPE cages

Smaller cages are cheaper than larger cages in absolute terms, but as they are three-dimensional structures, they follow the square-cube law for surface area to volume ratio. This states that when an object undergoes a proportional increase in size, its new surface area is proportional to the square of the multiplier and its new volume is proportional to the cube of the multiplier. The following table illustrates this:

Table 2: Illustration of the square-cube law

Multiplier	Length	Width	Height	Area of each side	Total area	Volume contained
1	1	1	1	1	6	1
2	2	2	2	4	24	8
3	3	3	3	9	54	27
4	4	4	4	16	96	64
5	5	5	5	25	150	125
6	6	6	6	36	216	216
7	7	7	7	49	294	343
8	8	8	8	64	384	512
9	9	9	9	81	486	729
10	10	10	10	100	600	1000

Note: A cube has six faces. As each dimension of a cube is the same, the area of each face is the square of the length of one dimension. The total surface area is the sum of the area of six sides. The volume is the cube of the one-length dimension. For a small cube the surface area is relatively high compared to the volume contained, whereas for larger cubes, the volume is considerably higher in relation to the surface area.

The square-cube law is significant concerning cage cost as most of the cost of the cage is linked with its total surface area. Most of this is netting, with only one side (the surface collar) being the most expensive in material terms. The cost of the moorings is also related to the surface area as it is the increase in drag forces on the higher surface area of the net and floats that require stronger moorings. A broad principle, therefore, is that larger cages will be cheaper per m^3 of water enclosed than smaller cages. However, as the chart below illustrates (taken from sample cage prices in Kenya), there can be significant variation, especially when switching from one type of cage construction to another.

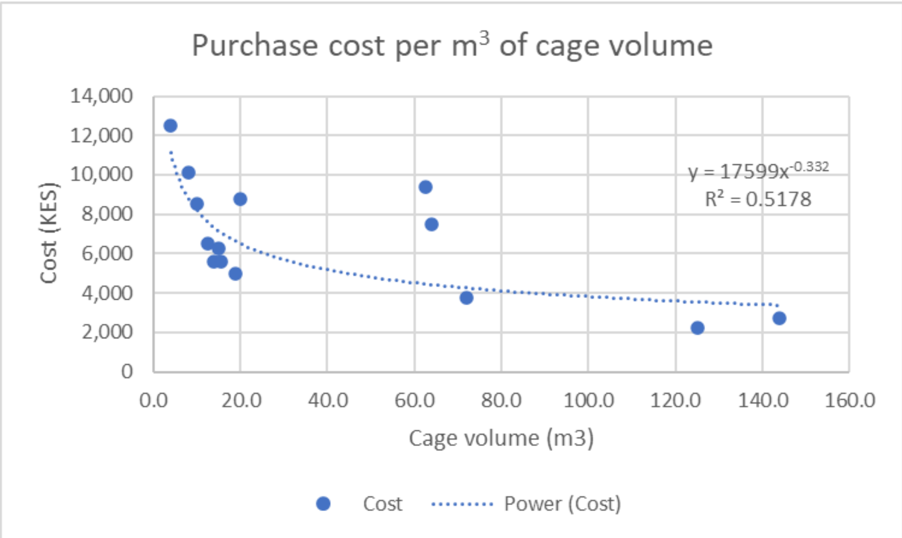


Figure 7: Example analysis of cage purchase cost in relation to cage volume

This analysis suggests that larger cages would be preferable to smaller cages from an economic perspective. However, larger cages need to be stronger, so material prices increase. Managing cages also becomes more difficult as nets for large cages are very heavy and beyond a certain size will require mechanical assistance for lifting. The size and expense of ancillary equipment such as boats will also increase with larger cage sizes.

The higher ratio of net area to volume enclosed for small cages can also have advantages. Adapting the previous illustration of the square-cube law to show just the five submerged sides of a cubic cage we get the following:

Table 3: Illustration of decreasing net area to volume with increasing cage size

Cage size	Net area (m^2)	Volume (m^3)	Area/volume
1 x 1 x 1 m	5	1	5.00
2 x 2 x 2 m	20	8	2.50
3 x 3 x 3 m	45	27	1.67
4 x 4 x 4 m	80	64	1.25
5 x 5 x 5 m	125	125	1.00
6 x 6 x 6 m	180	216	0.83

As water flow through the cage net is essential for supplying the fish with oxygen and removing waste metabolites such as ammonia and carbon dioxide this should be more efficient with smaller cages. Smaller cage nets will also be easier to clean, which is important as biological fouling and blocking of nets can be a major problem in some waters. The benefit of small cages is therefore that they can safely hold a higher biomass (or density) of fish per cubic meter than larger cages, at least from a physiological perspective. There may be wider behavioural and welfare issues, although farmers have also reported that with higher densities, there is less variation in fish size, possibly due to less opportunity for dominant behaviours to emerge.

The following chart illustrates this by charting the area of net per kilogram of stock at different stock densities (measured as kg/m^3).

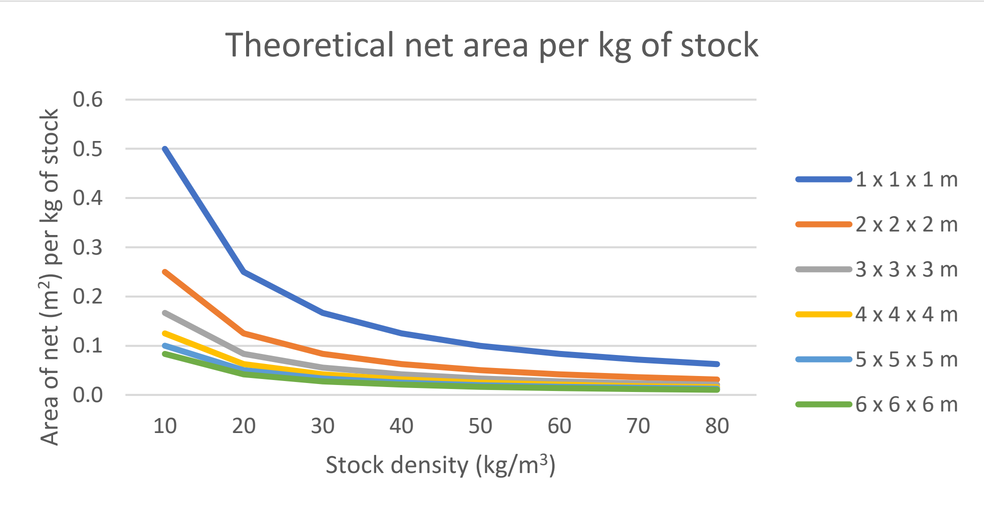


Figure 8: Theoretical net area per kilogram of stock for different sizes of square cages

For this reason, the use of small cages stocked at high density has proved popular in Lake Victoria and elsewhere – commonly termed LVHD (low volume high density) cages to contrast with HVLD (high volume low density) cages. Stock densities up to 100 kg/m^3 have been maintained in LVHD cages[8]. Cages

[8] https://tilapialoversociety.com/2019/04/09/lvhd-tilapia-cage-farming-system-ronaldo-b-gitana/

of up to 3x3x3 m have been classified as LVHD, but smaller cages will be more effective providing they are moored at least 5 m apart to ensure good water flow to each cage.

Figure 9: LVHD cages

A survey of cage culture in Lake Victoria published in 2021[9] found the dominant cage type to be locally fabricated galvanised metal cages measuring 2x2x2 m (8 m^3). However, other sizes in common use include 3x3x2, 3x3x2.5, 5x5x2.5 and 10x10x4 m. High-Density Polyethene (HDPE) pipe cages are also increasingly used, most being circular with a diameter of around 18 m. Whilst smaller cages offer many advantages, especially for new farmers, the economy of scale effects can be important for profitability, so larger cages are likely to be more attractive to experienced farmers who are better placed for such an investment[10].

Cage type and dimensions also needs to be matched with the environmental conditions on the selected or available site. The first factor is water depth. Advice varies, with one guideline being that the depth of the cage should be no more than half the depth of water available. Others recommend a minimum of 3-5 m of water below the bottom of the cage (remembering that in larger circular cages the bottom of the net may extend well below the depth of the sinker tube. This is primarily to help avoid any accumulation of waste below the cages that affect the water quality within the cages. However, another consideration might be the depth of any thermocline in a larger water body and the occurrence of upwellings. Deeper water may be more exposed to wind and higher waves, and may also have higher current velocities, although the latter probably vary, at least seasonally.

Table 4: Suggested site selection criteria

Cage type/size	Depth guidelines: Optimum (suitable) (m)	Wave height guidelines: Optimum (suitable) (m)	Current velocity guidelines (cm/sec)*
Small (up to 100m^3)	15-25 (14-30)	<0.2 (<0.3)	3-40
Medium (100 – 1,000 m^3)	18-30 (17-35)	<0.3 (<0.4)	3-40

[9] Orina et. al. 2021
[10] Musa et. al. 2022 & Brande et. al., 2023

Cage type/size	Depth guidelines: Optimum (suitable) (m)	Wave height guidelines: Optimum (suitable) (m)	Current velocity guidelines (cm/sec)*
Large (1,000 -5,000 m^3)	18-30 (17-35)	<0.3 (<0.6)	5-40
Very large (over 5,000 m^3)	24-35 (23-40)	<0.3 (<0.8)	5-50

Source: Adapted from Asmah et. al. 2016, Asmah et. al. 2021 & Belal et. al. 2015.

A current passing through a cage is not essential for gas exchange and waste removal, but this will be more efficient as current velocity increases. Unless the velocity is especially high, cage groups should normally be arranged at right angles to the prevailing current to minimise current shading.

Cage nets

In many ways, the nets are the most critical element of fish cages. Firstly, they must be strong enough to resist damage as that can quickly lead to the escape of the entire stock. They should be near neutrally buoyant in water to readily hang in the right shape. They should be reasonably smooth to avoid damaging the fish. They should have adequate rope fittings to assist with handling (on larger nets). Most importantly, they should have as wide a mesh opening as possible for the fish being contained to ensure good water exchange. Closely linked with this is their tendency for fouling (build-up of algae and other organisms growing on the nets). This is a more serious problem in seawater, but any growth makes the nets heavier and blocks the openings, reducing the exchange of water and hence risking low oxygen conditions.

Figure 10: Different types and grades of netting.

The most common materials for cage nets are polyamide (nylon) and polyethylene (PE). Nylon nets can be coated with antifoulant and are softer, but polyethylene is now cheaper and stronger so if often preferred. For aquaculture, it is important to look for knotless netting, as knotted netting can more easily damage fish. The twine is also normally twisted multifilament rather than monofilament, which is harder for the fish to see and again more likely to lead to injuries. Consideration can also be given to UV resistance which can be improved in some materials by additives or coatings. Ropes on cages are usually polypropylene (PP) or polysteel (PS).

Figure 11: Attaching nets to simple metal frame cages

Netting is usually constructed to be used oriented to show the mesh as diamonds. This means it can be stretched both vertically and horizontally, with the diamonds elongating and closing to achieve that. The degree to which the diamond pattern is stretched is measured as the vertical or horizontal hanging ratio, which is the length of the net when it is in position, divided by the fully stretched length. A ratio close to one suggests there is little to no stretch and the net is fully open, whilst lower numbers indicate more stretch and smaller spaces for water to pass through. This is also termed “net solidity” as water currents will be increasingly deflected around the cage rather than through the mesh. The reduction in current velocity passing through a cage net can be measured as the transmission factor. The greater the resistance the net offers to the current, the greater will be the forces acting on the net and cage and hence also on the mooring system.

Figure 12: Netting in normal orientation

In order to maintain a high hanging ratio, many net suppliers cut and reorient the net so as to hang “on the square” rather than “on the diamond”, such that weights on the net will keep the net open rather than tending to stretch and close it.

Mesh sizes are commonly measured as the distance between the opposite ends of a mesh when it is stretched. However, the bar length (or square measure) is more frequently used to specify the mesh size for aquaculture nets, so it is important to check which dimension is being used as the full mesh size is usually approximately double the bar length.

Figure 13: Netting in square orientation

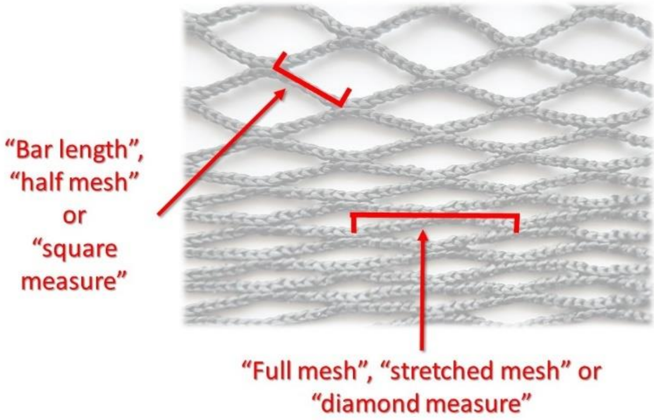


Figure 14: Net measurements

In general, it is desirable to use the largest mesh size possible for the fish in the cage to maximise water flow through the net. However, the primary function of the net is to prevent the escape of fish, and with some fish in the cage being smaller than others, it is generally necessary to be somewhat conservative when selecting mesh size. Changing the net for a larger mesh size during the growth period is a common operation. The new net is deployed outside of the existing net and the old net is then removed.

As a rough guide, a 0.5 cm bar net is used for fish between 0.5 g and perhaps 10-20 g. A 1 cm bar mesh is then used up to around 200 g and then a 2 cm bar mesh to at least 400 g. Larger mesh sizes can be used beyond that weight. A general rule f thumb (which may not always apply) is that the bar mesh size should be no more than 25% of the length of the fish. The chart below shows this maximum bar mesh size against fish length and weight.

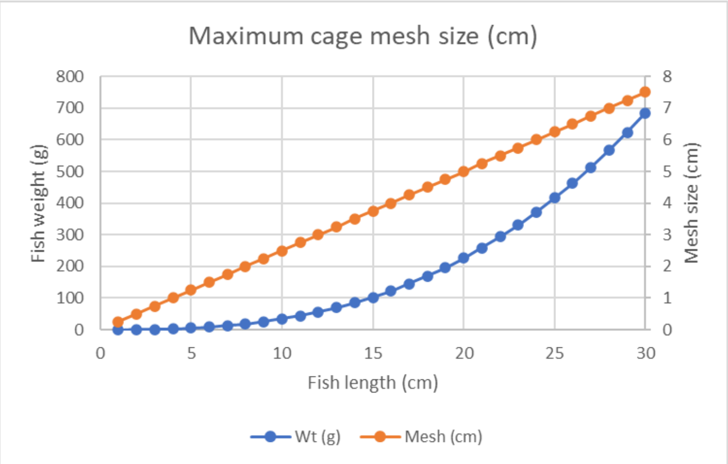


Figure 15: Generalised relationship between fish total length and weight, and maximum bar mesh size for containment (cm)

Figure 16: Locally made concrete net weights

It is important to keep the net under tension so that it maintains its shape and open structure. This is done using weights attached to ropes to which the net is also attached (i.e. the weight should be taken on the ropes not the netting itself). Some systems use small concrete weights, whilst plastic cages in particular, tend to use a "sinker tube" which is a plastic pipe formed into a circle the same diameter as the surface tube, but usually a narrower pipe which contains a heavy chain or other weight. That is suspended below the cage net to maintain net shape.

As indicated previously, net panels will reduce the current velocity, with smaller mesh sizes and fouled nets having a greater impact. This can be measured as the transmission factor:

$$Qc = Vt \times Ac \times Ft$$

Where:

Q_c = Flow through cage, m^3/sec

V_t = Tidal velocity (usually minimum, or say 10% of maximum), m/sec

A_c = Cross-sectional area of open cage netting across tide stream, m^2

F_t = Transmission factor (velocity through cage mesh/V_t).

Transmission factors for aquaculture cage nets are typically between 0.5 and 0.7, although this can reduce to 0.2 to 0.3 for heavily fouled nets. Besides increasing the supply of oxygen and removing carbon dioxide and ammonia, water currents also force the fish to exercise more. This can have a beneficial impact on fish growth, feed conversion and flesh quality. As a general guide, water velocities of between 0.5 and 2 fish body lengths per second. Hence greater velocities are desirable for larger fish. For a juvenile tilapia of 10 cm, this translates to 5-20 cm/sec. This is somewhat below the optimum of 35 cm/sec found by Belal (2015) for fish of this size.

However, higher current velocities can also lead to greater distortion of the net which reduces both the available volume and effective surface area for water exchange.

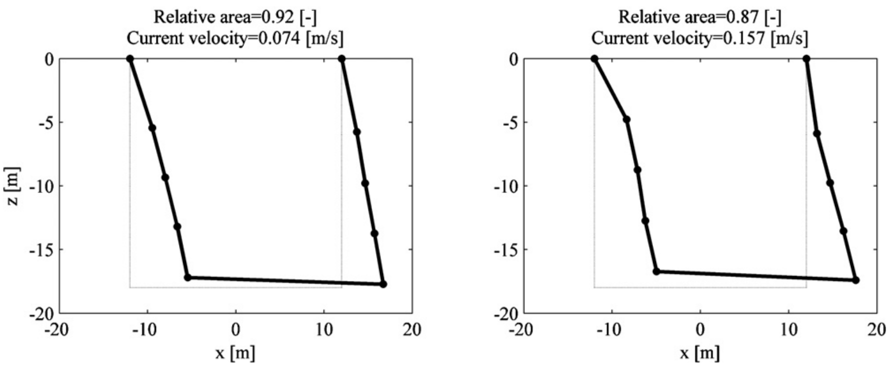


Figure 17: Illustration of net distortion (large salmon cages) under different current regimes (Source: Lader et. al. 2008)

The amount of distortion of the net can be reduced by adding more weight to the sinker tube[11]. However, even a current of 13 cm/sec can result in a 20% loss of cage volume with 50% of cage volume lost between 0.5 and 1 m/sec. The presence of

[11] López et. al. 2015

fouling on the nets will increase this further[12]. Currents also increase the load on the mooring system. As these forces are proportional to the square of the velocity a doubling of velocity from say 5 to 10 cm/sec will result in a fourfold increase in drag forces on the mooring system.

Before leaving the subject of nets, allowance should be made for anti-predator nets. These are required over the top of cages to prevent predation by birds, and sometimes underwater around the cage or cage group to protect against aquatic mammals or predatory fish.

Further considerations for cage selection

There are a good number of books and manuals providing more detailed guidance on cage design, material choice and mooring systems etc (see “Further Reading” at the end of this manual). There are also commercial equipment suppliers who can provide a complete range of services. The main thing to remember is that there is no perfect system, only the best system for your particular needs. Each design or selection criteria generally comes with a trade-off, so understanding these in the context of your situation and site is important. Over-arching considerations for instance include trade-offs between labour and capital. Which is most limiting? If funds are available and labour is in short supply or expensive, then investing in mechanisation will be a sensible strategy. If funds for investment are low and labour is available at a relatively low cost, then employing more people and only buying basic equipment may be preferable.

When purchasing equipment, consider whether to spend more on higher quality components that will last longer and reduce the risk of failures that could result in the loss of valuable stock. On the other hand, if selecting such equipment requires taking on large loans with high interest rates, then there is an opposite risk of any failure resulting in an inability to repay the loan perhaps leading to the collapse of the business or worse if other loan guarantees have been provided.

Smaller cages will be easier and more flexible to manage, but as the number increases, they will become less efficient than larger cages and more expensive to operate. Smaller cages will also be easier to install, requiring less sophisticated mooring systems. However, larger plastic cages in particular are much better able to cope with storm conditions and therefore less likely to be damaged with loss of stock when such events occur.

One essential at any level of investment is to consider staff safety and welfare. Ensuring cages have adequate anti-slip walkways and secure handrails is both important and may be a legal requirement. Boats must also be adequately specified, and staff have life jackets and other safety equipment with training in their use.

Stocking the cages

Production cycle

All tilapia hatcheries use ponds or tanks for early fry rearing. The absolute minimum size for transferring to cages is regarded as 0.4 – 1g (using a 0.5 cm mesh net). This is just after the completion of sex-reversal where that is practiced. Fish of this size will be the cheapest per individual (e.g. KES 3 to 10 (US$ 0.03 to

[12] Gansel et. al. 2015

0.1)). Other farmers will prefer a slightly larger fish of 2-3 g which will be more robust with a lower mortality rate when stocking to cages. However, these will be more expensive (e.g. KES 15-20).

There are then two common strategies for subsequent grow-out. The first is to maintain the fish within the same cage (although changing the mesh size periodically as needed). This has the advantage of minimising stress on the fish and hence possible mortalities and also reduces labour requirements. However, it does not utilise the available cage volume very efficiently and allows the variations in individual fish sizes to become quite large.

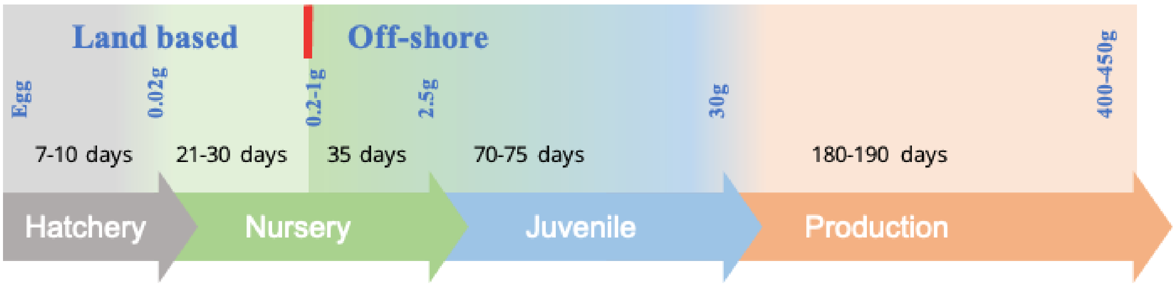


Figure 18: Generalised production cycle for cage reared tilapia

An alternative strategy is to use separate cages for the nursery/juvenile stage and the production/grow-out stage. This makes more efficient use of cage volume but requires handling the fish at the time of changeover, which can lead to increased mortalities. Typically, this is done when the fish reach 30-50g. If the fish are also graded, variation in size can be reduced and they may also be re-counted allowing more accurate calculation of feed quantities etc. This strategy could be followed by a single operator, or by different operators specialising in either the juvenile or production phase.

The spreadsheet model potentially allows two phases to be modelled by using different scenario sheets for each phase. However, as the model only allows for one size of cage, it is more likely that each phase would be modelled separately.

Small fish strategies

The primary aim of the spreadsheet model and associated research is to examine the potential for producing and selling smaller tilapia, perhaps in the range of 100 – 300 g. This can be achieved by terminating the grow-out period at an earlier stage. In that case, if the fish are stocked at a conventional density, they will be harvested well before they reach a maximum stock density. This offers the possibility of stocking at a higher density initially, to produce more fish overall with the same cage volume, but at a lower individual weight (Strategy S3-Short in the spreadsheet).

If a higher stocking density is used at the start of the cycle, but the cycle length is not reduced, the resulting fish will probably be smaller than if a lower initial stock density is used, but larger than “small fish”. This is strategy S2-Double in the spreadsheet.

More interesting to many producers may be the option to stock at a higher density initially and then have an interim harvest to remove a proportion of the fish at the small size and grow the remainder to a standard large size. This is strategy S4-PartialHarvest in the spreadsheet. This is potentially attractive as it optimises production capacity and produces additional income which can at least help to fund the feed costs for final grow-out[13].

Consideration might also be given to whether mixed-sex fry might be used. It has become standard practice for hatcheries to produce all-male fry as these generally show better growth performance over the full culture cycle and avoid any problems with fish spawning especially for pond culture. In higher-density cage culture where there is an intention to produce an intermediate harvest of smaller fish, a mixed-sex population can show comparable performance[14]. This could be of interest where mixed-sex fingerlings are cheaper to purchase or there are regulatory or ethical reasons to avoid the use of hormones for sex reversal.

Other considerations

The source of seed is crucial since the quality of the stock and the health of the fry directly affects both the growth rate and survival rate of fish during the whole growing period. Purchasing cheap fry from an uncertified source is likely to be a false economy.

Figure 19: Pond reared fry ready for transfer to nursery

The growth rates of tilapia have been substantially improved through selective breeding programmes and several such stocks are now available in Kenya and Sub-Saharan Africa. For instance, the Kenya Marine and Fisheries Research Institute and Kenya Agriculture and Livestock Institute have developed the Sagana F-8 strain of Nile tilapia which achieved an average harvest weight of 450 g in 7 months from a start weight of 1 g in cages with an average water temperature of 28°C[15] The Sagana F-8 strain reportedly also has good feed conversion rates and resistance to common disease problems[16]. However, it is important to remember that in breeding for a small number of specific traits, some other traits such as resistance to novel diseases might be weakened.

It will usually be desirable to purchase fry or fingerlings from a local hatchery to minimise transport costs and more importantly, stress, which can increase the likelihood of significant losses after stocking.

Guidelines on handling fry and introducing them to cages can be found in some of the manuals listed at the end of this manual.

[13] Kaminski et. al. (In Press)
[14] Bostock et. al, 2022
[15] https://www.kmfri.co.ke/images/pdf/Improved%20tilapia.pdf
[16] Abwao et. al. 2023

Feeding the fish

General considerations

Tilapia are opportunistic feeders that graze and naturally eat throughout the day. This can be taken as a guide to an optimum feed regime. Smaller but more frequent feeds produce better growth and feed conversion efficiency than a small number of larger feeds[17]. This is especially the case in the early fry and fingerling stages. Mechanical feeders can therefore give the best results, but require greater investment and reduce staff interaction with the fish, which can be very valuable for spotting any signs of problems and adapting feeding to actual conditions.

As there is very little natural food available for tilapia held at higher densities in cages, they need a fully formulated diet that provides for all their nutritional needs including protein, fats, vitamins, and minerals. Smaller fish generally require a higher protein diet than large fish. The choice of ingredients is important as it is the range and balance of amino acids within the proteins that are important, and similarly with the lipids that contribute to the fat content. Some potential ingredients contain anti-nutritional components that can reduce the growth performance of the fish. The length and conditions of storage of both finished feed and feed ingredients can also substantially affect nutritional value. Standards for tilapia diets have been published by some countries including Kenya[18], and these can be used as a guide when comparing feed specifications.

The manufacture of diets is also important as the nutrients will be more available to the fish if ingredients are finely ground and some at least are cooked or heat treated. Other variables include the shape, size and hardness of the pellet, how easily it crumbles, its stability in water and its density (whether it floats or sinks slowly or rapidly). Whilst on-farm production of feed is possible, it is very difficult to achieve the quality and performance of diets produced by specialist companies. For that reason, good quality commercial diets are recommended for cage culture when available.


Figure 20: Example of different feed grades

Feed is the single largest proportion of operating costs, so a high priority for profitable operation should be to minimise waste. This leads to practical guidelines such as ensuring the pellets are not washed out of the cage before the fish have a chance to eat them. Floating feeds have the advantage that they are easily monitored, but are most affected by wind so can be blown quite quickly through the side net. Tilapia are also more naturally mid-water feeders, so a slow-sinking diet is preferred by many farmers. These also need to be monitored to ensure it is being eaten before drifting out of the cage due to currents or sinking through the net bottom. This becomes increasingly difficult with deeper nets as much of the volume of the cage becomes invisible from the surface. Some cages include a smaller internal feed ring which constrains the feed so that it is less easily lost from the cage. However, this can encourage

[17] Abdel Fattah, 2021, Fava et. al. 2022
[18] KS 2289-1:2017 (https://webstore.kebs.org/index.php?route=product/product&path=1&product_id=11942) Draft version available at https://members.wto.org/crnattachments/2016/TBT/KEN/16_4795_00_e.pdf

dominant behaviour as the stronger fish dominate access resulting in some fish being underfed.

Many farmers aim to feed the fish to match their appetite, adding more until they show little interest. This usually gives the best growth rates, but less efficient feed conversion rates[19]. As fish grow, they need a lower percentage of their body weight each day in feed to maintain optimum growth. Also important is the size of the feed pellets or crumbs. If the diameter is too large for the fish mouth, the fish will be unable to eat until it has started to break down and already lost valuable nutrition. Tilapias are more able to cope with feed that is below optimal size, but some feed efficiency could still be lost.

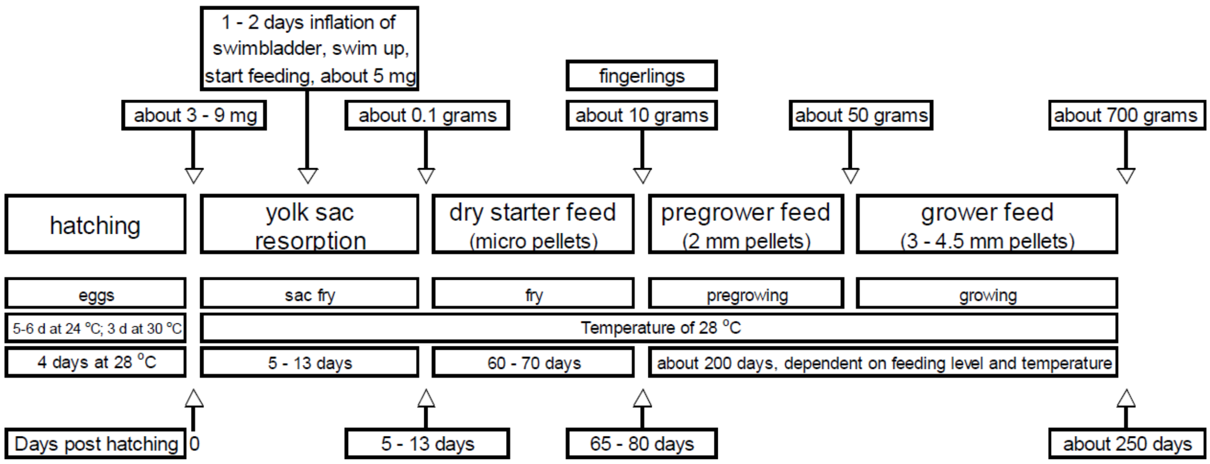


Figure 21: The usual pattern of feed types and sizes during the lifecycle of tilapia (Source: Terpstra, 2015)

Table 5: Feed manufacturer recommendations on feeding frequency

Fish size	Suggested feeding frequency
0 – 1 g	8 x per day
1 -2.5 g	6 x per day
2.5 – 10 g	4 x per day
10 – 25 g	3 x per day
> 25 g	2-3 x per day

Source: Skretting
Note feed amount should adjusted depending on feeding response.

Experienced farmers will use fish behaviour as a guide to feeding. Fish crowding near the usual place where feed is introduced is probably a sign of appetite, whereas fish that are well spaced throughout the cage may indicate satiation (although note fish also crowd at the top when there is a shortage of oxygen!). Observing behaviour whilst feeding can also be helpful as fish that are spitting pellets back into the water and/or ignoring them could indicate problems with palatability including pellet hardness, diet formulation problems or improper storage leading to the growth of moulds for instance. A variety of camera systems are available these days to help with observing fish behaviour whilst feeding.

[19] Cadorin et.al. 2021

Figure 22: Good storage of feed is essential to reduce spoilage and contamination. Can you identify good and poor practice in the examples above?

Modelling feed and growth

To model growth, the spreadsheet assumes that growth is proportional to feed intake with the relationship depending on the efficiency that the feed is used. This can be expressed as:

SGR = SFR/FCR

Where SGR is the Specific Growth Rate which is a measure of the percent increase in weight per day. It can be calculated from sample fish weights as follows:

$$\text{SGR, \%/day} = \left(\left(\frac{Wt_{end}}{Wt_{start}}\right)^{\frac{1}{DAYS}} - 1\right) * 100$$

Where: Wt_{end} = fish weight at end of period

Wt_{start} = fish weight at start of period

Days = Number of days between start and end dates

Note: The fish weights are usually average weights based on a random sample

SGR is based on an exponential growth curve, so future fish weights can be calculated using the following formula[20]:

$$Wt_{end} = Wt_{start} * e^{(LN((SGR/100)+1))*Days}$$

[20] See Crane et. al., 2020 for further discussion of SGR

As fish growth rarely follows an exponential curve, especially over a longer period, the spreadsheet only uses this calculation to predict the weight the next day. This allows the SGR to be adjusted throughout the growth cycle to provide a better representation of actual average growth.

SFR is the Specific Feed Rate which is the amount of feed fed per unit of time (usually the day) expressed as a percentage of the biomass being fed

$$SFR = (\text{Feed fed}/\text{Biomass}) * 100$$

FCR is the Feed Conversion Ratio which can be calculated by dividing the SFR by SGR:

$$FCR = SFR/SGR$$

This means that providing two of SGR, SFR and FCR are known, the other can be easily calculated.

The better-known and more immediately applicable formula for FCR is:

$$FCR = (\text{kg of feed used}) / (\text{kg of biomass gain})$$

Or $$FCR = (\text{kg of feed used over period})/(\text{End biomass (kg)} - \text{Start biomass (kg)})$$

An FCR of 1 would indicate that 1 kg of feed yields 1 kg of fish biomass, whereas an FCR of 2 would mean that 2 kg of feed is required to produce 1 kg of fish biomass.

It is worth remembering at this point that FCR is a measure that includes the actual conversion rate of feed into fish and the loss of conversion due to uneaten feed. Therefore, a high-quality feed fed with a lot of wastage may appear to have a higher FCR than a poorer-quality feed that is fed with no wastage, although the underlying conversion rate would be superior.

These FCR equations do not take into account any mortalities or other fish removed from the cage (e.g. through harvesting) between the start and end date. It is common therefore to consider two measures of FCR:

1) Economic FCR (*e*FCR) which is the actual end result:

$$eFCR = \text{Wt feed fed} / (\text{Biomass}_{end} + \text{Biomass}_{harvest} - \text{Biomass}_{start})$$

Note the weights should all be in the same units (e.g. Kg) and over the same duration. Biomass is the average fish weight x fish number

2) Biological FCR (*b*FCR) which includes mortalities and gives a better measure of conversion of feed into biomass where there are significant mortalities:

$$bFCR = \text{Wt feed fed} / (\text{Biomass}_{end} + \text{Biomass}_{harvest} + \text{Biomass}_{mortality} - \text{Biomass}_{start})$$

*e*FCR is used in cost calculations whereas *b*FCR is used when evaluating diets and husbandry practices.

Use of feed tables

Most major manufacturers of fish diets will also publish feed tables to guide the amount to feed each day, i.e. the SFR. By combining this information with expected FCRs, the tables can be used to predict SGR and hence the daily growth increment of the fish. This is the method used in the spreadsheet.

A typical feed table is shown below. The column on the left shows a range of water temperatures. As fish are cold-blooded, their metabolic rate and hence feeding and growth rates depend on temperature.

They have an optimum temperature (27°C in the example below) where feed consumption is highest. Above and below this temperature feed intake is reduced and growth will be slower.

The row at the top shows a range of fish weights (g). The SFR (daily feed rate) can then be read from the table by reading across from the correct temperature and down from the fish weight. E.g. for a fish of 25g and a water temperature of 27°C, the recommended feed rate is 7.1%. i.e. if the biomass was 500 kg the feed amount would be (500/100) *7.1 = 35.5 kg.

Table 6: Biomar Feed Table (from Terpstra, 2015)

Temp. °C	Fish weight (g)								
	4	**8**	**15**	**25**	**35**	**60**	**100**	**160**	**300**
17	1.72	1.77	1.63	1.58	1.34	1.23	1.06	0.9	0.76
19	2.51	2.66	2.53	2.38	2.06	1.85	1.58	1.35	1.14
21	3.45	3.4	3.26	3.16	2.68	2.46	2.11	1.8	1.52
23	4.31	4.25	4.07	3.95	3.34	3.08	2.64	2.25	1.9
25	5.22	4.67	4.26	4.17	3.62	3.31	2.84	2.42	2.04
27	7.01	7.64	7.41	7.1	5.53	3.63	2.91	2.48	2.09
29	6.91	6.78	6.48	6.39	4.99	3.2	2.74	2.33	1.97
31	3.54	3.5	3.35	3.25	2.75	2.53	2.17	1.85	1.56
33	1.56	1.54	1.47	1.43	1.21	1.12	0.96	0.81	0.69

The first question that usually arises when using these tables is how to deal with intermediate values, i.e. a temperature of 26°C and a fish weight of 10g. The widely used convention (including in the spreadsheet) is to use the lower value until the higher value is reached. i.e. the feed rate for 25g fish is used for fish of 26-34 g, and the feed rate for 25°C is used for 26°C and until 27°C is reached.

Using the relationships between SFR, FCR and SGR explained previously, plotting the feed table on a chart for any selected temperature shows that the SFR declines as the body size increases, as does SGR.

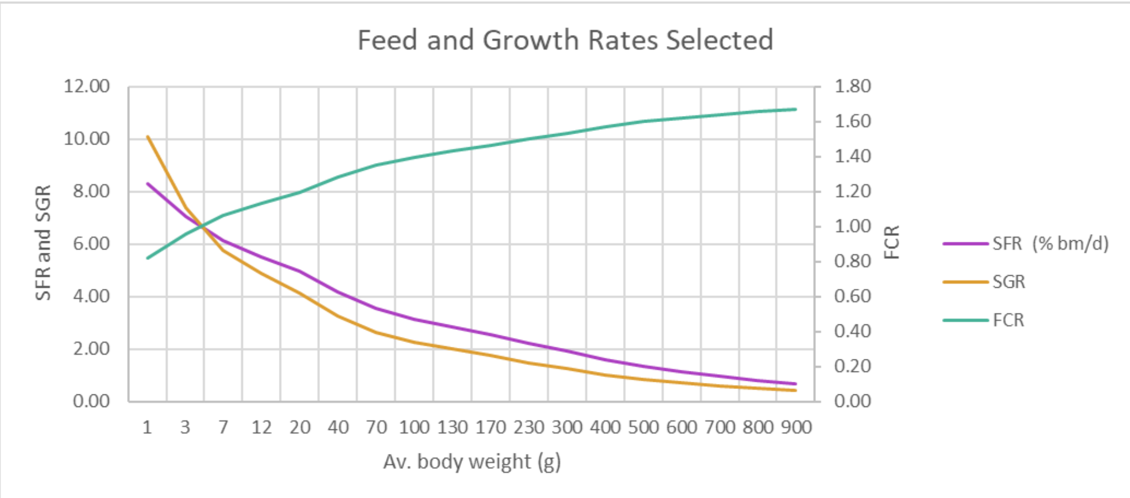


Figure 23: Example plots of SFR, FCR and SGR against average body weight

Conversely, FCR generally increases with increasing body weight. However, it is the least predictable parameter as it depends on the efficiency of feeding as well as dietary qualities. The spreadsheet allows the use of an exponential formula to simulate rising FCR values or previous farm data can be entered directly. The use of an exponential formula is not very satisfactory, especially towards the minimum and maximum sizes within the range, but it provides a straightforward approach where minimal prior data is available.

Environmental factors

Some environmental considerations

In this section, we mainly consider environmental variables which affect the fish farm. There are many concerns about the effects of the fish farm on the wider environment, but they are beyond the scope of this manual, except that the spreadsheet model could be used to provide some of the information that might be needed in an environmental impact assessment, such as the amount of feed to be used.

The spreadsheet model assumes consistent environmental conditions. Whilst a major lake does tend to have quite a stable environment in comparison with small earth ponds, it does nevertheless vary and sometimes by a large degree. The first consideration is water temperature. As already discussed, this varies depending on location, season, and time of day.

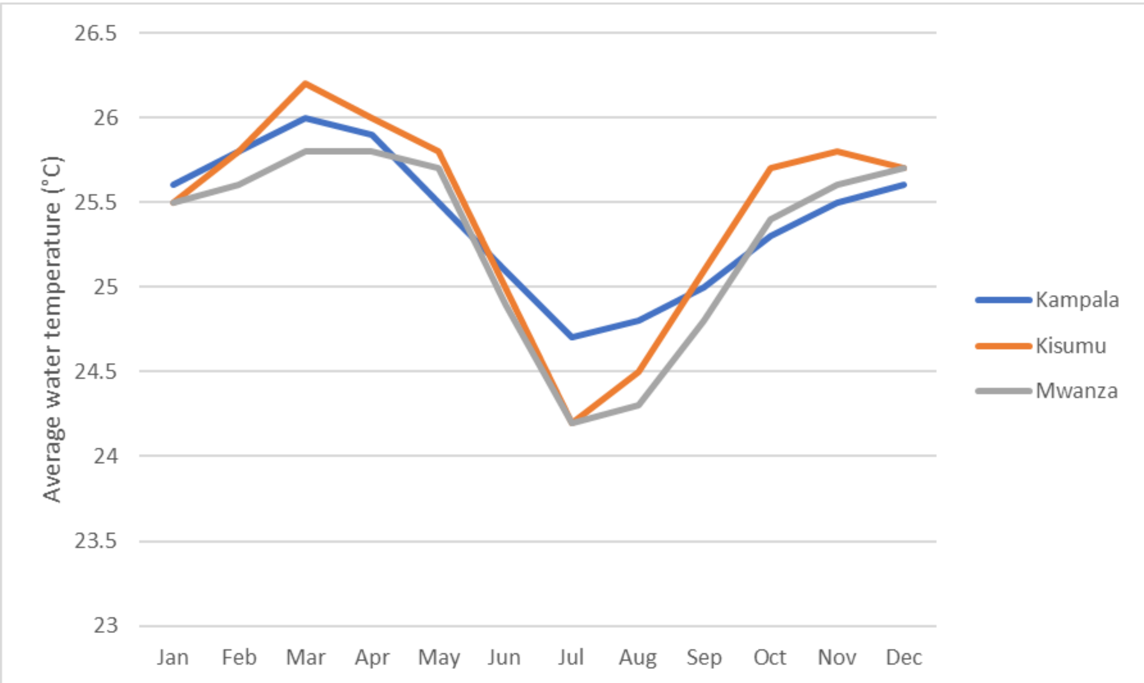


Figure 24: Average water temperatures in Lake Victoria at major towns

Chart source[21]

Temperature patterns in more sheltered locations might vary significantly where there are areas of shallow water or inflows of water from other sources. The chart below shows average recorded temperatures at a farm in comparison with published average minimums and maximums at the nearest

[21] Data source: https://seatemperatures.info/

major town. Significant variation can be seen in July when the surface water temperature at the farm was more than two degrees above the reference town average and 1.5 degrees above the average maximum.

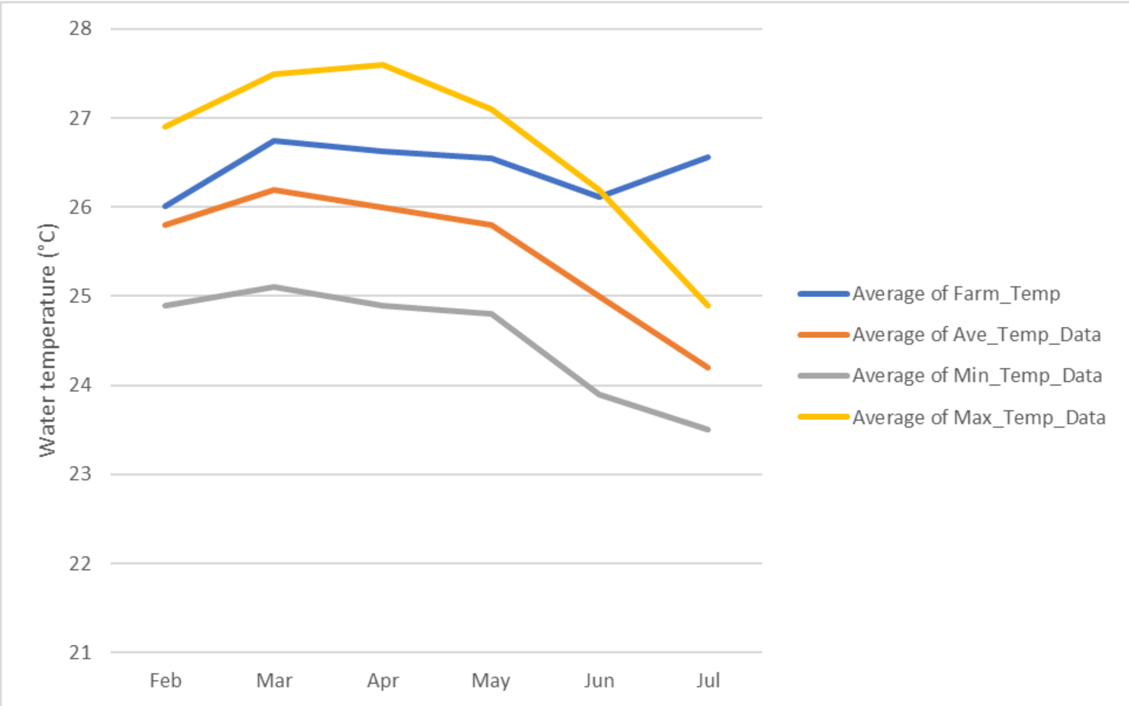


Figure 25: Actual average farm surface temperature data compared with published monthly minimum, maximum, and average temperatures for nearest major town

A further consideration is dissolved oxygen levels. Most of the time these will be much more stable than in small ponds, but Lake Victoria, for instance, has yearly cycles of thermo-stratification (September-May) and mixing (June-August), as well as an underflow stream that causes upwelling and downwelling locations. Upwelling currents, for example, can bring anoxic bottom waters to the surface that can result in significant fish mortality.

Figure 26: Wastes can pollute the water leading to algal blooms, water quality deterioration, and eventual fish mortalities

In shallow areas, there may be excessive growth of macrophytes or microalgae which can lead to high oxygen concentrations in the day, but low oxygen concentrations at night and potentially almost complete deoxygenation if there is a massive die-off. Where that occurs, there may be other water quality problems such as increased concentration of ammonia or nitrite. In some areas, water quality might also be influenced by inflowing water from streams, rivers or groundwater.

If a site is considered unsuitable for fish farming for any part of the year (e.g. due to regular algae blooms or known risks of deoxygenation or low/high temperatures), this period can be excluded in the spreadsheet model via the setting “If you can't grow fish all year, how many days per year are not suitable for farming?” The model does not help with scheduling production around these dates, but it enables them to be excluded when multiplying up production per cycle to predict an overall production per year.

Once a cage fish farm is operating, there will be a gradual rain of fine organic particles from the cages to the sediment underneath due to uneaten feed and fish faeces. Often the water currents close to the lakebed are very weak and the organic matter accumulates, over time leading to substantial changes in the benthic biota. There can also be chemical changes if the sediments become anoxic. If such sediments are disturbed, they can cause localised deoxygenation and potential fish kills.

In terms of the wider environment, some consideration needs to be given to the presence of predatory species – particularly birds, but potentially mammals, reptiles (e.g. crocodiles) or larger predatory fish (e.g. Nile Perch). There may also be the risk of theft from cages, either at a low level (e.g. by staff) or through more organised and targeted activities. Extra costs may need to be incurred to install protective measures, or mortality assumptions adjusted when modelling the system. Pathogens and other disease agents are also an environmental consideration. Intensive aquaculture in an open environment provides opportunities for pathogens and unless adequately managed, can lead to substantial problems for aquaculture producers. The list of references and further reading at the end contains several texts on these topics.

Monitoring and modelling environmental factors

It is important to note that for simplicity of use, the spreadsheet model assumes constant environmental conditions. Of course, as outlined above, this is not the case. It is important to take account of this limitation and adjust scenarios as necessary.

For any aquaculture operation, it is highly recommended to monitor all major environmental variables and keep good records so that the farming environment can be better understood and the reasons for poor growth or unexpected mortalities investigated.

In lake environments, the most important variables to measure in addition to temperature are oxygen and water clarity – the latter usually being a proxy for microalgae growth. Microalgae can be measured chemically by analysing for Chlorophyll, optically using a fluorometer (or more crudely using spectroscopy) or most simply assessed using a Secchi disk. This is a weighted metal disk painted with a black-and-white pattern to make it easy to see. It is lowered into the water on a rope or cable which has depth marks. When the disk is at the point where it disappears from view, the submergence depth is noted. Shallow depths indicate high concentrations of particles in the water (e.g. microalgae) whereas deeper readings indicate low concentrations. Secchi readings can be affected by other types of water colouration, the light and surface conditions and even the person taking the reading, so can only be used as an indicator. However, when algal blooms occur, a Secchi disk will give a good indication of the severity. The chart below illustrates routine monitoring of one site using a Secchi disk. Note the algae bloom in October resulting in decreased visibility.

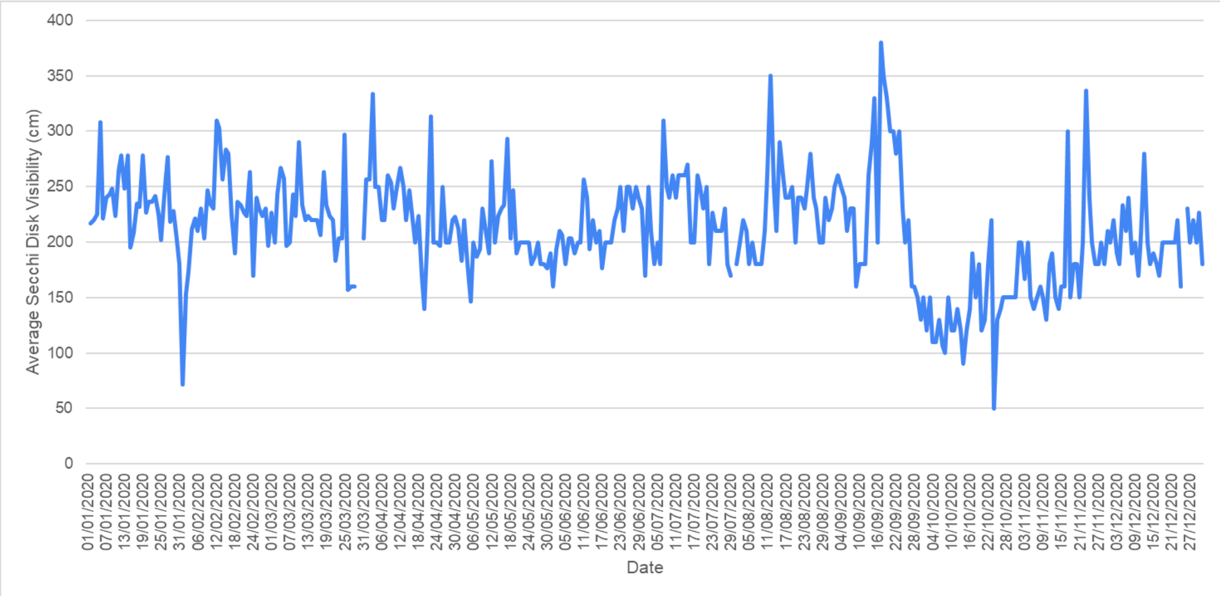


Figure 27: Example of daily secchi disk readings at one site in 2020

Even more important is routine monitoring of oxygen concentrations. Readings can be taken at different depths, at different times of the day (or even at night) and both inside and outside the cages. The reading inside the cage is most important, but comparison with the outside reading will give an indication of the degree to which cage nets may be blocked or fish densities become too high.

In waters containing plants, and especially microalgae, the oxygen concentrations will be lowest in the early morning (around dawn), so that is a critical time to check.

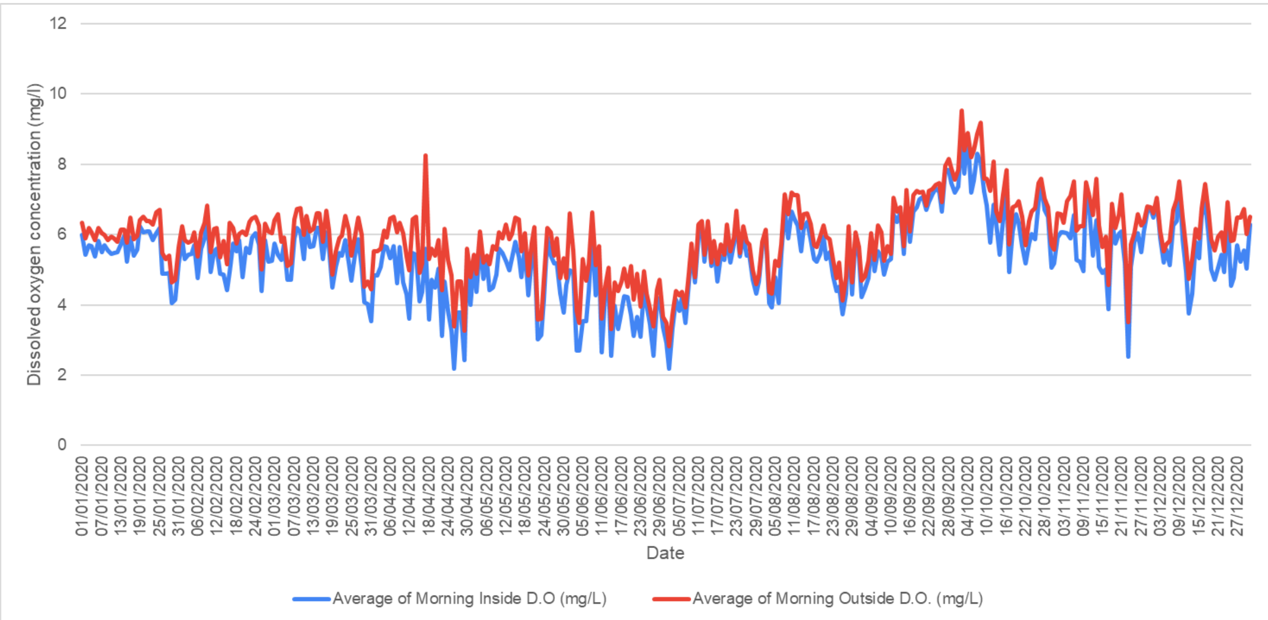


Figure 28: Example morning oxygen concentrations at a site in 2020 (inside and outside of cage)

If the oxygen concentration in the afternoon is much higher than in the morning it is likely to be due to the contribution of oxygen from microalgae and plants. If the oxygen is lower in the afternoon, especially inside the cage, it may indicate high stock densities or poor water exchange through the cage nets.

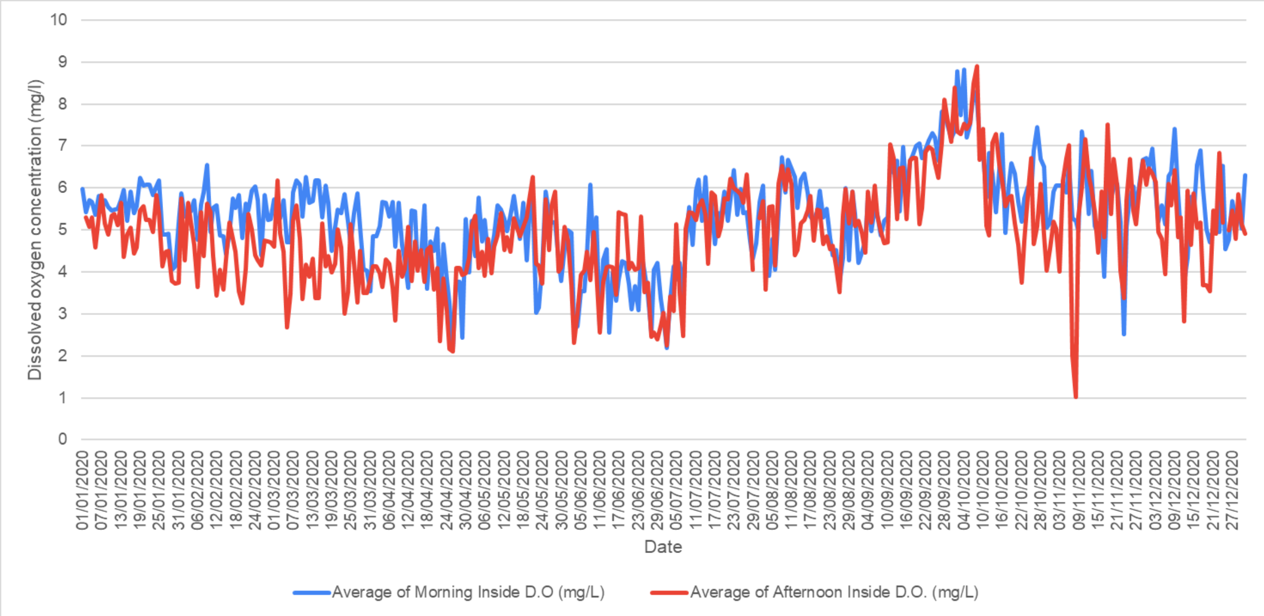


Figure 29: Example oxygen concentration inside a cage comparing morning and afternoon values at one site in 2020

Due to differences in biomass, feed patterns, net cleanliness etc., oxygen values can be significantly different between cages even when they are moored next to each other. By routinely recording oxygen and relating this to stock and husbandry records, farmers can better understand which factors are most important for future management.

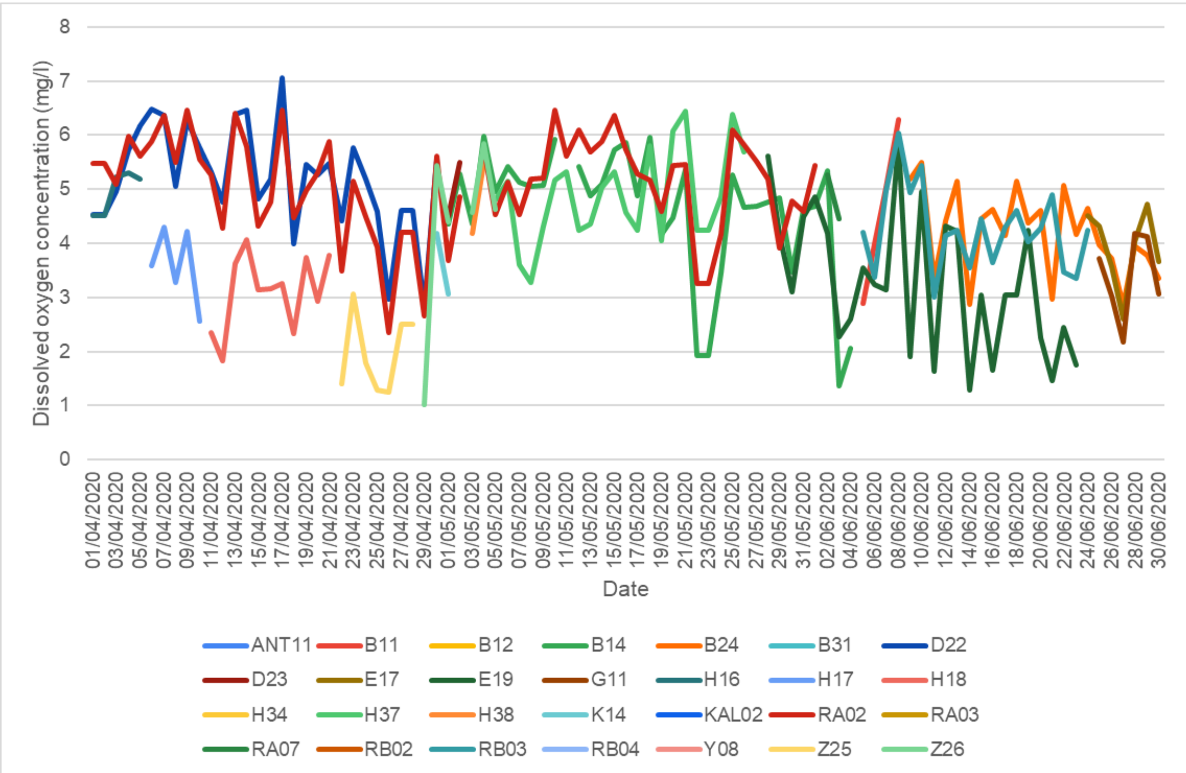


Figure 30: Example of morning inside cage oxygen concentration for different cages at the same site

As mentioned previously, the cleanliness of the nets can have a substantial impact on water circulation and hence oxygen concentration within a cage. It is therefore important to ensure nets are regularly cleaned and an appropriate mesh size is used.

Figure 31: Cleaning cage nets

The spreadsheet model does not have a direct function for simulating dirty nets, but you can reduce the assumed growth rates by using a lower assumed water temperature. In reality, the risk is that poor water quality will lead to higher food conversion ratios, so increasing the assumed FCRs might be a better approach as this would maintain the level of feeding, but reduce growth.

The spreadsheet does have a function for reducing growth rate at higher stocking densities (GrowthAdjust sheet). This effect can be observed due to poorer water quality or possibly increased stress and behavioural issues. The function works by reducing the specific growth rate (SGR). This could be used to help adjust the model to better represent actual data where growth reduction at higher stock densities is observed.

Monitoring and modelling the stock

Good daily record-keeping is essential for gaining greater insight into the farming process and key variables for individual sites and management strategies. With experience, they can also provide early warning of emerging problems and can help refine the assumptions made in the strategy spreadsheet. A range of commercial farm management software is also available, with all reputable products likely to prove highly cost-effective when used properly to guide management decisions.

Perhaps the first and most important stock parameter to consider is fish numbers, as minimising losses during the production process is one of the most basic steps towards ensuring profitability. To continue the focus on nets from the previous section it is very important to regularly check for, and repair, any holes that appear. These can be due to handling damage, predators, or general wear and tear in waves and currents. Ensuring the net is properly tensioned, but that loads are distributed by ensuring they fall on the net ropes rather than the net panels is very important. Small holes can lead to "unexplained losses" – differences between the number of fish stocked and the number harvested, after subtracting known mortalities. In more severe cases, virtually the entire stock of fish can be lost.

Predation and theft are the other main causes of unexplained losses and again close attention to the choice of anti-predator nets and how they are deployed and kept at the correct tension is important. The spreadsheet model does not have functions for escapes or predator losses, but the mortality rate assumptions can be changed, and to some extent, when these occur. Losses of larger fish represent a much greater financial loss than smaller fish as much more has been invested in getting them to that size.

The second most important stock parameter to monitor is the average (and preferably variation) fish weight. This is usually checked by periodically taking sample weights, where at the most basic level, a sample of fish is removed from the cage, weighed, and then counted back into the cage. Several samples of this type are taken, and the mean weight of the fish is then calculated. A major drawback of this approach is that fish can be damaged and certainly highly stressed during this operation. The use of an anaesthetic can help, but new technologies for measuring fish using underwater video cameras and computer analysis are gradually being introduced.

A key point to remember, however, is that any measurements of stock (or environmental conditions) are subject to error. This is from three main sources. Firstly, accuracy – how close is your measured value to the true value? When weighing a fish for instance, how accurate are the scales? Do they show the weight to the nearest 1/10th of a gram, or the nearest gram, or to the nearest 10 g or nearest 50 g etc? When you count fish is it done very accurately, or quickly, with the possibility of error? The second source of error is precision. How close are repeated measurements of the same thing to each other? Perhaps when weighing fish there is a variable amount of water also weighed each time? Or perhaps different people will record different Secchi disk measurements under the same conditions. The third source is sampling errors. Unless you measure the whole population, you are taking a sample, usually a relatively small number of fish in relation to the whole population. Are you getting a truly random sample? Are there any biases in the way the sample is taken, e.g. if you just net fish swimming close to the surface will they tend to be larger more dominant fish or smaller weaker individuals? Unless they are a true random sample (of a sufficient size) there will be some sample bias that will affect the accuracy of the population estimate.

When estimating biomass, there are errors associated with the measurement of fish weights and the measurement of fish numbers. These errors can make biological indicators such as FCR and SGR appear quite variable, when they may be relatively stable; so this should be taken into account when trying to interpret on-farm monitoring data.

As an example, if you had a fish cage containing 10 tonnes of fish and your sample weight error margin was 5% and your estimation on numbers had an error margin of 10% the overall error margin for biomass estimation would be ±11.2%[22]. i.e. you might estimate the biomass in the cage to be anywhere between 8.9 and 11.1 tonnes. If you happened to have a high estimate one month and a low estimate the next month it might appear that the fish are not growing well, when in fact it is just an artifact of sampling and measurement errors.

The impact of errors can be reduced by increasing the number of individual samples within a population. However, this will have both operational and fish welfare implications, so a balanced approach will need to be taken.

[22] Total error is calculated as SQRT(weight error^2 + number error^2)

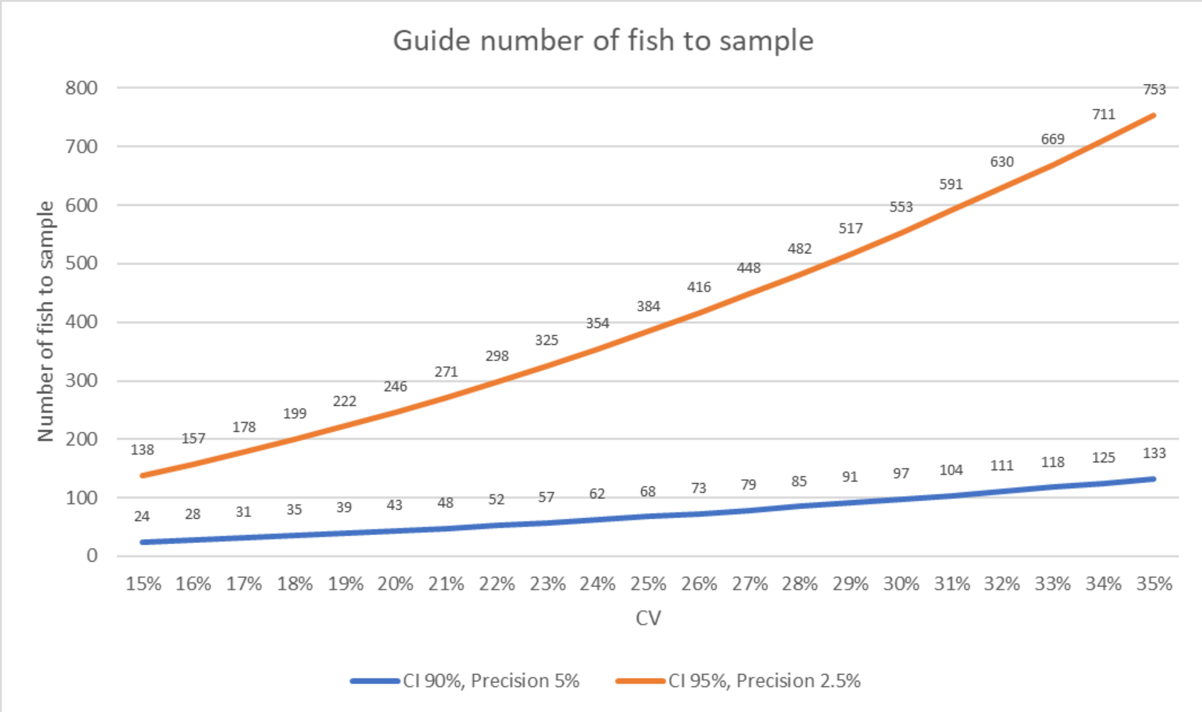


Figure 32: Illustration of increasing number of fish that need to be sampled (e.g. for weight) to maintain accuracy (measured as Confidence Interval) and precision as the spread of fish sizes increases (indicated by increasing Coefficient of Variation)

(Source: Talbot, 2020[23])

The number of fish that need to be sampled to be confident that an average weight estimate for instance is within 95% of its true value will depend on the spread of sizes present in the cage. In the spreadsheet, the spread of fish weights is modelled using the coefficient of variation (CV), which is calculated as:

CV = (Standard deviation / mean)

It therefore follows that:

SD = (mean * CV)

CV is usually multiplied by 100 to express as a percentage.

The effect of different CV values is shown in the chart above.

Most aquaculture systems are managed to reduce the CV by regularly grading fish to maintain batches of similar size. This is particularly important in the early life stages of species that are more prone to cannibalism.

An example of routine grading of fish and re-splitting into different cages can be found in Brazil (See diagram below). This has the advantage of minimising size variation within a cage and also maximising the production capacity of the volume available.

[23] Dr Clive Talbot, Aquaculture Research Services, Unpublished lecture notes.

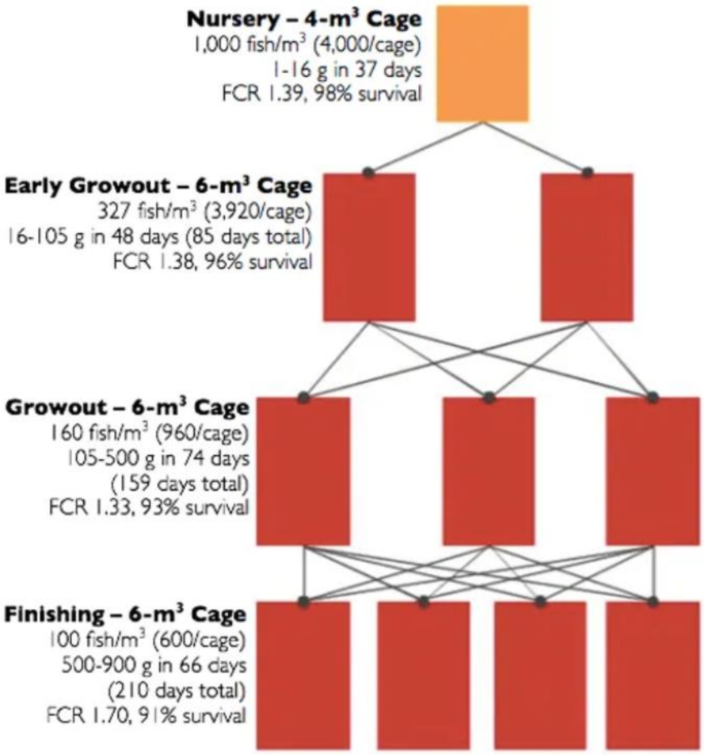


Figure 33: Schematic of production system for tilapia in cages in Brazil (Source: Nunes, 2010)

Grading is achieved through the use of a variety of devices, mostly involving bars spaced to allow smaller fish to pass through whilst larger fish are retained[24].

However, grading stresses and can damage the fish, so is usually followed by several days of elevated mortalities. A more recent innovation in cage design in Brazil allows gentler passive grading with claimed improvements in survival and growth[25].

Figure 34: Example of size variation from within a single batch

[24] See https://www.fao.org/fishery/docs/CDrom/FAO_Training/FAO_Training/General/x6709e/Index.htm
[25] Waycott, 2018

In the context of this manual and spreadsheet, producing a wider range of fish sizes in each batch could be a useful strategy for both maximising survival and enabling farmers to serve a more diverse range of markets with different-sized fish. The spreadsheet allows the exploration of production strategies using different CV values.

Harvesting and Marketing

Harvesting – full and partial harvests

Prior to any harvesting operation, the fish should not be fed for around 2 days to allow the gut to clear[26]. Small cages can be harvested quite easily by hand, either by lifting and removing the entire net, or lifting it sufficiently to enable fish to be scooped out with a hand-net.

Larger cages usually require the use of mechanised equipment. A common protocol is to use a separate crowding net within the cage and then remove the fish using a brailer net suspended from a mechanical davit/crane. The brailer net is similar to a large hand net but has a release mechanism in the bag so that the fish can be released from the net. However, this is a bad system from a fish welfare perspective as fish are highly stressed and often injured through contact with the net or the weight of other fish on top of them. A better system is the use of a fish pump. This still requires fish to be crowded to a reasonable degree, but the journey to the point of slaughter is less stressful or damaging. High stress during harvesting is known to affect flesh quality as well as fish appearance, so there are many good reasons to minimise this. Best practice guidelines also promote the use of diffused oxygen into the water during the crowding phase.

Figure 35: Using a crowding net in the cage, followed by a brailer net to lift the fish to the boat

[26] National Fisheries Development Board, 2016.

Figure 36: Emptying a brailer net into 1 tonne plastic bins containing ice

Figure 37: Using a fish pump to harvest a cage – fish are drawn into the pipe and transported in water to the harvest point

Both fish welfare and product quality are considerably improved through good stunning and slaughter practices. Stunning is defined by the European Commission as "any intentionally induced process which causes loss of consciousness and sensibility without pain, including any process resulting in instantaneous death[27]" Traditionally, fish caught in any quantity has simply been asphyxiated, by being kept out of water and often under the weight of other fish. For warm water fish, it has become common practice to place the harvested fish in iced water which provides a stunning effect and helps to maintain quality. However, more recent research has shown this technique to be only partially effective[28] and the main focus for development now is electro-stunning[29]. A percussive blow to the head, if well delivered, can be an effective means of stunning, but is impractical for larger numbers of fish unless mechanised and automated.

In principle, immediately following stunning, the fish should be killed, and cutting the gills to allow the fish to bleed out is both effective and best for subsequent flesh quality and product shelf life. However, this should not be done where the blood can drain back into the lake due to the risk of spreading disease as well as organic pollution. For practical reasons, therefore, the most common approach is to harvest the fish into an ice slurry where they are partially stunned and then asphyxiated. Full processing can then take place on shore.

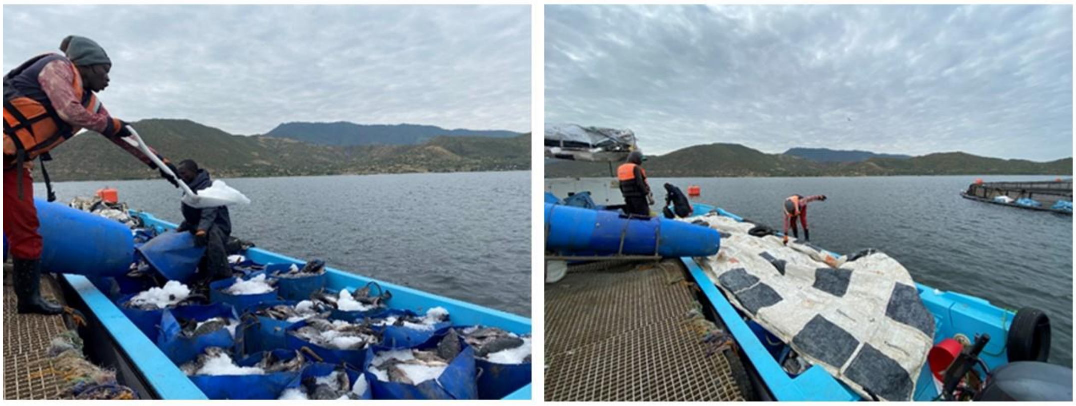


Figure 38: Freshly harvested fish placed in bags with ice and then covered with tarpaulin to protect against the sun

[27] European Council Regulation 1099/2009 on the protection of animals at the time of killing
[28] Pedrazzani et. al. 2020; Aquaculture Advisory Council, 2017.
[29] HSA, 2018

There are various attractions to undertaking a partial harvest to leave some fish in the cage for harvesting at a later date. The most obvious consideration is the volume of fish that can be readily sold. Over-harvesting risks financial loss as excess fish may need to be discounted to sell before they perish. There may also be a partial harvest to follow one of the suggested strategies in the accompanying spreadsheet. i.e. starting with double the normal stock density and then conducting a partial harvest of 50% of the fish approximately halfway through the production cycle. This provides a harvest of smaller fish that can find a ready market amongst more price-sensitive consumers (see below). It also re-sets the stock density to allow the remaining fish to grow at their optimum to full harvest size.

However, there are also risks and downsides to carrying out a partial harvest. Firstly, all the fish must be starved before the harvest, so some growth is lost in the remaining fish. More seriously, the remaining fish have been subjected to considerable stress and possible injury during the harvest procedures and so are more susceptible to infectious diseases. The mortality rate can therefore be expected to rise, at least for a short time after the partial harvest.

Processing

Advice on the handling of harvested fish, including relevant food regulations, can be found in some of the texts suggested in the "Further Reading" section at the end of this manual. Here we just deal with the issues concerning processing and marketing that are relevant to the assumptions and costings in the spreadsheet model.

The spreadsheet assumes all the fish are sold in the same condition and point in the value chain. It is therefore important to be clear which point of reference you are using. The main options concerning processing fresh fish are:

3) Unprocessed "round fish", as harvested.
4) Gutted – Fish are cut open and all viscera removed
5) Gutted and gilled – Viscera and gills are removed
6) "Dressed" – Gutted fish have heads, fins, scales removed and tails trimmed
7) Skin-on fillets
8) Skin-off fillets

Where processing is carried out to stage 5 or 6, there is a primary processing facility to clean and gut the fish which are then taken to a second specialist processing facility for filleting. We are ignoring the options for freezing, smoking, or drying the fish to preserve shelf-life as these are not commonly used for locally produced tilapia at the moment. The model was designed assuming processing would be limited to options 1-3, but with care can be used for further processed fish.

Figure 39: Gutted whole tilapia on ice

The main consideration for modelling is that as the fish is processed the weight is reduced in relation to the harvested fish. Indeed, even without any obvious processing the weight of a round fish when sold will be lower than the same fish when it was alive before harvest. This is due to the loss of weight on bleeding and some further drying of the fish so that it loses water content. Removing the gut and gills further reduces the weight of the fish. The percent losses at each stage depend on the size and condition factor of the fish and the effectiveness of bleeding and gutting etc. The table below gives an approximate guide to the weight of different fish components[30], but you should take some measurements of your own and use those.

Table 7: Weight composition considerations for processing

Component	% of harvested fish wt.	(Your data)
Moisture	2	
Blood	3	
Viscera	15	
Gills	2	
Head	16	
Fins and tail	3	
Scales	5	
Frame	19	
Skin	3	
Fillets (skin off)	32	
Total	100	

You can use this information to calculate an adjustment factor:

Table 8: Weight adjustment factors for processing

Product	% of original weight	Reduction %*	(Your data)
Whole round fish	95%	5%	
Gutted fish	86%	14%	
Gutted and gilled fish	84%	16%	
Dressed fish	52%	48%	
Skin-on fillets	33%	67%	
Skin-off fillets	30%	70%	

* Use this figure in the spreadsheet setup

The adjustment factor is used to adjust the harvest weight to the weight of fish sold in the spreadsheet model. It is therefore important to also ensure that the sales prices entered into the spreadsheet match the degree of processing. i.e. if the price you use is for gutted fish, the spreadsheet should include the appropriate adjustment factor for that product form.

The financial analysis section of the spreadsheet should also be completed to match the product form, i.e. to include the appropriate processing costs. This includes a variable cost per kg of product processed and a fixed cost element consisting of the annual rent of facilities and an additional sum to account for other fixed costs such as maintenance, standing charge for power and any licencing fees.

The financial section also includes a variable cost per kg of product for distribution, so again, this should match the point in the value chain that the product price is taken from.

A final point to consider is the timing of any post-harvest processing. As with all fish, tilapias are affected by rigor mortis which causes the body to stiffen, making processing operations impossible. The onset of

[30] Adapted from Mohamed et. al. 2022

rigor mortis depends on temperature and other factors but for fish slaughtered in an ice slurry and kept at around 4°C it is around 4 hours after death[31]. The fish can remain in rigor mortis for up to 3 days, again depending on storage temperatures and other factors. It is probably optimal therefore to aim to conduct any primary processing within a short time after death and use the rigor period for distribution to other parts of the value chain. Following rigor mortis, the flesh will continue to leak water and protein, therefore losing weight and nutritional value until it is either consumed or spoils completely.

Packing and transport to different markets

Until relatively recently, ice was not readily available to fish producers in Africa. A lack of familiarity with iced fish may lead some consumers to prefer non-iced products. However, the use of ice and refrigerated transport where available makes a major difference to product quality, safety and particularly shelf life. Market chains have now developed, particularly in urban centres, where the use of ice and refrigeration are expected. However, particularly for smaller fish sold into local markets close to the farm, simpler methods of protecting the fish from the heat of the sun and preventing drying may be quite adequate. Where flake or crushed ice is available, fish should ideally be transported in insulated boxes with a weight ratio of 1:1 fish and ice, although 2:1 may be adequate for shorter journeys.

The spreadsheet model requires only the input of a cost per kg of fish sold for distribution. If you are using wholesale prices in the spreadsheet, then you should include the cost of transporting fish to that market. You can calculate this cost as follows:

Table 9: Example calculation of delivery cost per kg

	Example Data	Your Data
Input data		
Cost of insulated boxes (KES/day)	20	
Capacity of insulated boxes (kg)	20	
Additional box-days per shipment	1	
Cost of ice per kg (KES)	20	
% ice in box	40%	
Van - load capacity (kg)	4,000	
Van - fixed cost per day (KES)	3,600	
Van - variable cost per km	30	
Van days per delivery	1	
Van km per delivery	150	
Calculated data		
Van - fish capacity (kg)	2,400	
Number of boxes needed	200	
Cost of boxes (KES)	8,000	
Amount of ice needed (kg)	1,600	
Cost of ice (KES)	32,000	
Total cost of van (KES)	8,100	
Total cost of shipment (KES)	48,100	
Cost per kg of fish delivered (KES)	**20**	

[31] Viegas et. al. 2013

This example assumes the use of reusable insulated transport boxes that are rented at a daily rate. The number of days costed are the days required for delivery plus the additional box-days per shipment. The van also has a fixed cost per day and a cost per km. If a refrigerated van is used, then the van cost would likely be higher, but insulated boxes and ice would not be necessary. The aim is to work out the total cost of a shipment and then divide that by the kg of fish delivered. That figure can be used within the spreadsheet when using fish prices obtained at markets incurring delivery costs.

Figure 40: The use of a refrigerated truck and plastic boxes to distribute fish to retail outlets in Kenya

Markets and demand

General principles

It is a central theory of conventional free market economics that the market price of a commodity product depends on the balance of supply and demand as shown in the chart below. If there is an increase in the quantity supplied, the producers will need to reduce the price to attract more buyers to sell all that they produce. On the other hand, if there is a reduction in supply, the demand at the previous price will be higher than the available supply and so the producers will be able to increase the selling price.

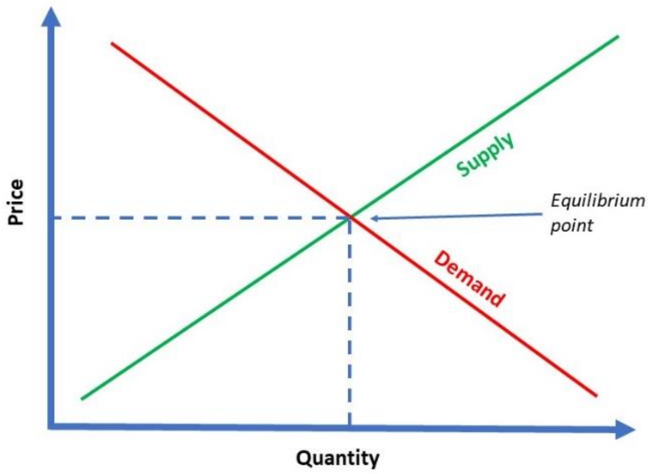


Figure 41: Typical theoretical supply and demand curve indicating price as the mechanism for achieving a balance between the two

As supply and demand continually fluctuate, particularly in different physical markets which may be visited by different types of consumers, more work is needed to understand the best opportunities for producers. For instance, can you regard tilapia as one product? Is a 200 g tilapia the same product as a 500 g tilapia? Is a cleaned and gutted tilapia on ice the same product as a whole tilapia that has not been stored in ice? They will be separate products in that they achieve different prices on the market, but because consumers can readily substitute one form of tilapia for another, the market prices are likely to be closely linked. Is tilapia from one producer the same as from another? Producers often try to "brand" their product and differentiate it from other suppliers as a basis for achieving a higher market price than the average.

A producer is generally aiming to maximise profit, which can be defined in simplest terms as:

Profit = Total Sales Income – Total Costs

However, it can also be useful to consider profit as:

Profit = Margin per unit x Number of units

Where:

Margin per unit = Sales price per unit – cost to produce each unit

In this case, a convenient unit is kg of fish.

Using the second equation above, it can be seen that profit can be increased by increasing the margin made on each unit, by increasing the number of units sold, or both simultaneously. This can be important when considering market opportunities. For example, transporting fish to a city market may add cost and therefore reduce the margin per unit, but if it allows many more units (quantity) to be sold, the overall profit will be higher.

In some circumstances, a similar principle may apply to the production and sale of small fish. The margin per unit sold may be lower than for bigger fish, but perhaps the quantity can be higher, especially when selling into more price-sensitive markets.

Spreadsheet financial indicators

Whilst the spreadsheet is not designed to produce accurate costings, it can be used to explore quantity and margin effects for different production and sales scenarios. The sales price (per kg) is one of the most important input variables to the model and therefore one of the first things to check and adjust to match your knowledge of the target market. In most markets, the price per kilogram that can be obtained varies depending on the size of the fish (total weight per individual).

Table 10: Spreadsheet setup table for sales price per kg

Size Range (g)	Label	Wt class	Price per kg
0-99	0+	100	219
100-199	100+	200	271
200-299	200+	300	344
300-399	300+	400	358
400-499	400+	500	365
500-599	500+	600	363
600-699	600+	700	378
700-799	700+	800	388
800-899	800+	900	405

The Operating Cost sheet of the workbook provides a snapshot of the production cost per kg to compare with the sales prices.

Table 11: Calculation of production costs

Cost of production	
Production only	KES/kg
Variable costs only	310
Variable & fixed costs	314
Variable, fixed and overheads	315
Production & distribution	
Variable costs only	320
Variable & fixed costs	324
Varible, fixed & overheads	325
Including equip. depreciation	341
Including equip. & other dep.	344

On the Comparison page of the spreadsheet, the breakeven price per kg is calculated – i.e. the minimum price at which the fish can be sold to avoid a loss.

Table 12: Other financial indicators shown on the comparison page of the spreadsheet

Other indicators		
Variable cost breakeven price per kg fish	319.66	KES
Total cost breakeven price per kg fish	349.64	KES
Breakeven yield (above total costs)	31,911	Kg/yr
Breakeven yield (above variable costs)	29,176	Kg/yr
Gross profit/loss per m^3	2,340	KES/yr
Net operating profit/loss per m^3	1,529	KES/yr
Overall profit/loss per m^3	-1,917	KES/yr

Below the breakeven prices are the breakeven yield, which is the amount of fish that has to be sold at the assumed price to realise a profit based on the calculated margin per kg. Below these figures, the unit of measurement is changed to consider the margins per m^3.

A more detailed analysis of the returns by cage and fish size is available on the scenario sheets. However, note that these do not include all costs, so can only be used for preliminary comparison between different strategies.

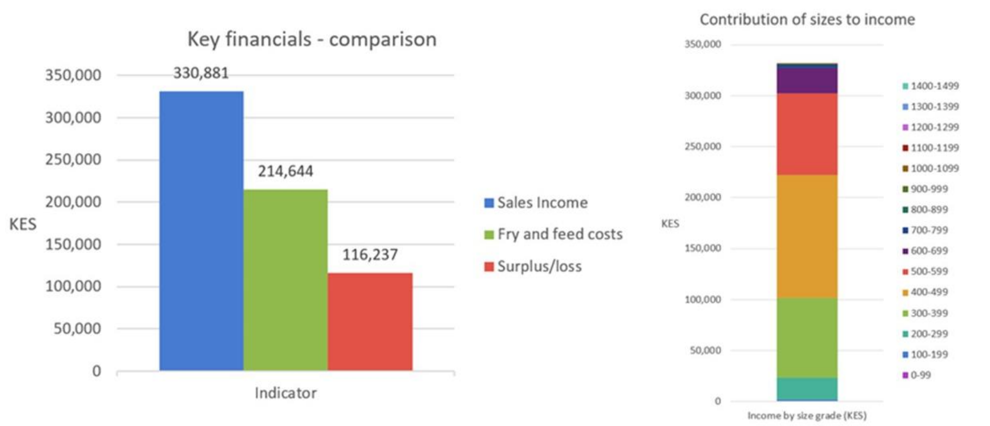


Figure 42: Charts providing analysis of income and major expenditure by strategy (left) and revenue by fish size category (right)

These financial indicators can be used alongside market studies and analysis to help optimise a farm production strategy.

The markets for different fish sizes

As discussed earlier, unless stocks are frequently graded and harvested at just the right time, a range of fish sizes will be available, although most are close to the average weight. A survey of fish traders in Kenya found few traders selling tilapia below 100 g in weight and the most common sizes were 300-400 g (size 3), followed by size 4 (400-500 g) and then size 6 (500 g+).

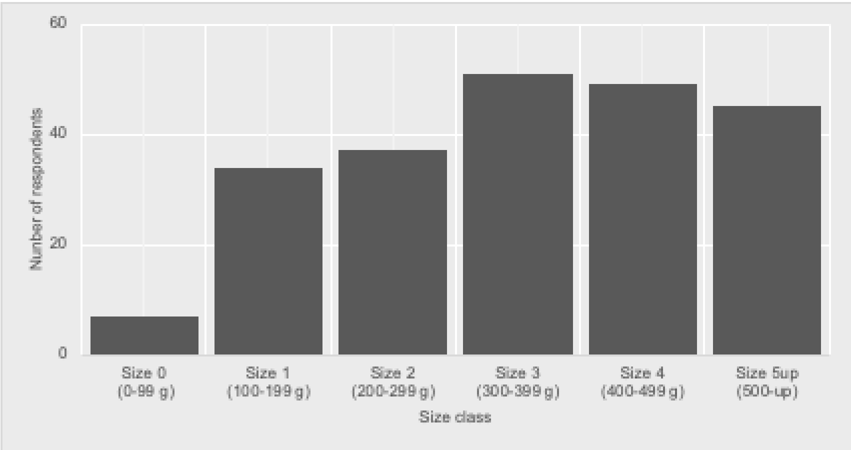


Figure 43: Frequency chart for sellers of different size grades of tilapia in Kenya

When interviewed, the traders reported that consumers prefer fish over 200 g. However, when a more in-depth study was conducted in rural Kenya, smaller fish (100-200 g) were reported to be the best seller to the most price-sensitive (worst off) consumers, and still had significant sales to consumers in the middle-income bracket. This suggests there could be a significant market for smaller fish provided they can be profitably produced, and such fish could make a very significant contribution to the nutrition and health of poorer consumers.

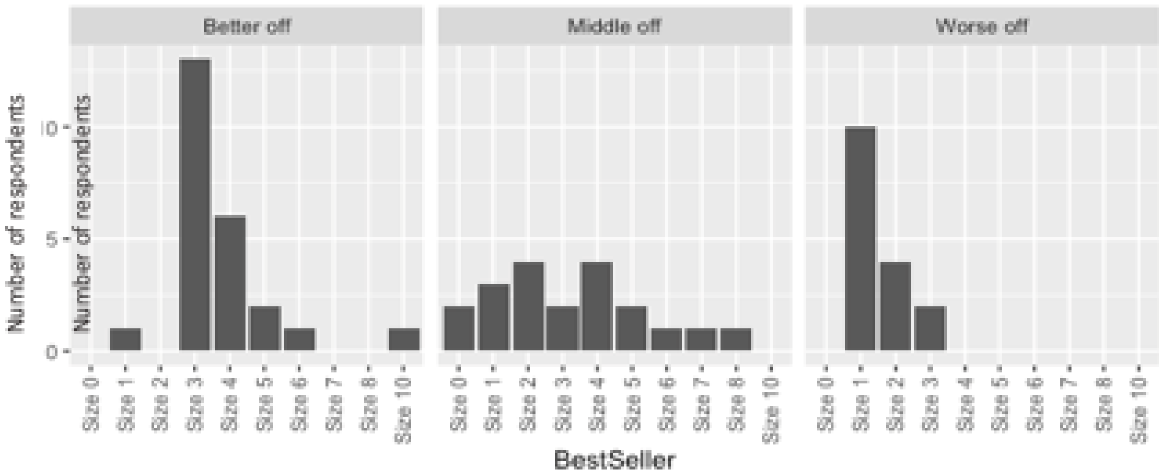


Figure 44: Best-seller size of tilapia of rural traders by market category. Size 0 (0 - 99 g), Size 1 (100 – 199 g), Size 2 (200 – 299 g), Size 3 (300 – 399 g), Size 4 (400 – 499 g), Size 5 (500 – 599 g), Size 6 (600 – 699 g), Size 7 (700 – 799 g), Size 8 (800+)

In general, a fish above 400 g is needed to produce fillets, which for consumers in Northern Europe and the USA for instance, would be the most preferred format. However, most tilapia in Africa is sold whole (usually gutted) and is served as a whole fish, one per person. For most adults, a 300-400 g fish would be considered adequate, and 400-500 g fish a very good portion. A 200-300 g fish might be ideal for younger family members, or poorer consumers who are aiming to buy a certain number of fish rather than a particular total weight. By contrast, in many parts of Asia, a larger fish is desired for a shared plate. Very small fish can potentially be consumed whole, which provides greater nutritional value per kilogram. However, this has not been a focus for producers so far.

Other market considerations

Returning to the issue of market price there are a few further considerations. Firstly location. Markets are associated with populations which may be small or large and vary considerably with respect to social mix and hence demand for different types and sizes of fish. Each market comes with a different cost to access, and potential quantity that can be sold.

Secondly, the quality of the fish. Primarily this refers to the freshness, as perceived by the buyer. A fish that has spoiled becomes worthless, whereas a supplier known to sell fresher fish will probably be able to charge a slight price premium. There may be other indicators of quality that consumers look for, such as skin colour, fin and skin condition, body shape etc. Cage-reared tilapia tend to be much darker than pond-reared tilapia, so it is worth investigating consumer perceptions and adjusting marketing plans and activities as appropriate.

Thirdly, consider the issue of convenience. Enabling the consumer to purchase their desired number of fish within their budget could be seen as part of this. Other common considerations include whether the fish is gutted or dressed, whether it is conveniently packed for the intended market and whether the purchase location is conveniently located for the intended buyers.

Fourthly consider market demand patterns. Are there any seasonal festivals where sales are likely to be higher, or the demand for larger fish increase? Or seasons when cheaper fish from the capture fishery are available and likely to depress the price of tilapia? Are there weekly patterns such as a preference for fish at the weekends, or monthly patterns such as increased expenditure on fish for workers who are paid at the end of the month?

Finally, consider the potential for differentiation and obtaining a price premium over other suppliers. Full branding can be expensive and best suited to individually packed products. However, buyers at all stages will value consistency and reliability of service, evidence of good management and quality control, and increasing adherence to ethical standards on animal welfare, labour rights, and environmental impacts.

Using the spreadsheet strategy tool

Introduction

The strategy spreadsheet has been developed to help farmers consider their basic strategy in terms of what size to stock, how long to farm the fish and at what average size to harvest. It is based on research conducted by the University of Stirling in cages at Victory Farms, Kenya.

Four basic strategies provide the framework for the spreadsheet model, but these can be modified by the user to give further options. The four strategies are:

1) Standard grow-out of stock to a harvest weight of around 500g
2) Double-density grow-out of stock resulting in a lower average harvest weight but greater numbers
3) A short cycle to produce smaller fish with an average weight of around 250g
4) Double-density stocking but a partial harvest of smaller fish mid-cycle and a second harvest of larger fish at the end of the cycle

The spreadsheet allows users to adjust parameters such as the size of fingerlings stocked, feed and growth parameters, and the cost of fingerlings, feeds, fuel and set-up costs, and sales prices achieved.

Users with multiple cages can assign different cages to the defined strategies and get an approximate overview of their expected production, costs and returns. Because these figures do not include all variables, they should only be compared with other results from the spreadsheet. i.e. by trying multiple strategies, a user can quickly assess which strategy or combination of strategies would be best for his site and circumstances.

Initial setup

To get started, open the spreadsheet file “Tilapia- Model-vXX.xlsm” (where XX is the current version number). You will need a full recent version of Microsoft Excel (e.g. Office 365 or Excel 2016). You will probably receive a warning message about unsafe content. You will need to allow the active content to use the navigation buttons within the spreadsheet.

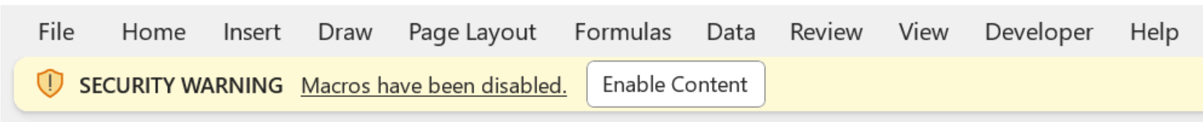


Figure 45: Example security warning when opening the spreadsheet

It is assumed that you are familiar with the basic use of Microsoft Excel. However, very little knowledge of Excel is required to use this tool. The main thing to note at the start is that the file is a workbook with many different pages (sheets). Each sheet can be found as a tab at the bottom of the screen. Start on the tab “0-StartHere”.

For first use, it is suggested that you just fill in the information in the first section of this set-up page. We will return to the advanced section later. You will see white rectangles containing numbers which you can edit. Any other numbers shown on this or other sheets are calculated and protected from direct alteration.

Tilapia Cage Farm Production Strategy Explorer

This tool allows you to quickly consider stocking and harvesting options
for small-scale cage-based farming of tilapia in Lake Victoria and similar water bodies

Start by answering the following questions:

What is the average water depth at your site? (m)	10	
How many cages do you have?	8	<< This model assumes all cages are the same volume
Are the cages rectangular or circular?	Circular	
If applicable, what are your rectangular cage dimensions?		
Length (m)	3	
Width (m)	3	
Depth (m)	3	
If applicable, what are your circular cage dimensions?		
Circumference (length) (m)	30	
Diameter (m) (calculated from circumference)	9.5	
Depth (m)	2.5	
Individual cage volume used in calculations is (m^3)	*179.0*	
If you can't grow fish all year, how many days per year are not suitable for farming?	0	
You have this numer of days available for farming each year	*365*	
What is the average water temperature? (°C)	26	*<< suggested value for Lake Victoria is 26°C - must be between 20 and 30°C*
Assume loss of weight between harvest and sales (%)	0.0%	

On the next 4 sheets there are 4 culture strategies (Scenarios) that you can explore:
By default these are:
1. Standard stocking density and harvest of larger fish
2. Double density stocking and harvest of larger fish
3. Double density stocking and harvest of smaller fish
4. Double density stocking with interim harvest of small fish

On the 5th sheet you can compare the results of these and allocate your cages to the different strategies

Figure 46: The Start Page with initial set-up options

The first question asks for the average water depth at the cage site (m). This is used further down the sheet as a basic check on site suitability. If cage depth is greater than one third of the water depth a warning message is displayed.

The next question asks how many cages you have. This information will be used later in the analysis. If you use more than one cage size it is suggested that you calculate the average volume and then adjust the dimensions in the next section to give this average. If you have a large number of cages and usually manage several in the same way, you could enter the number of cage groups here, although you will then need to enter cage dimensions that give the volume of the group and not an individual cage.

The next question asks if you have rectangular or circular cages. If you have both and the volumes are significantly different, it is suggested you run the model with one type of cage and then again with the other. However, you will have to keep a copy of your results and combine them manually. If they are close in volume, you can select either rectangular or circular and ensure the calculated volume equals the average cage volume.

For circular cages, you are asked for the circumference measurement in meters. This is the measure most often used by plastic cage suppliers as it is the length of pipe that is used to form the circle. Immediately below this number is the calculated diameter, which is often the more meaningful measure for farmers. If you know the dimension of the cages but not the circumference, you can either enter multiple guesses until the correct diameter is shown, alternatively use the following equation:

$$Diameter = \frac{Circumference}{\pi}$$

Where π (Pi) = 3.14

You also need to enter the cage depth. Especially for larger cages this is likely to be deeper at the centre. As cage nets are often distorted and cage volumes reduced through the effects of currents, it may reasonable to take the bottom of the side net as the depth of the cage. Alternatively, you could take the depth at approximately 1/3rd of the distance between the cage edge and centre as the mean depth.

If you select rectangular cages, you are asked for length, width and depth measurements to calculate the volume.

The next question is how many days per year are not suitable for farming. This is in case you are not allowed to culture fish during certain weeks of the year or choose not to due to climatic or other reasons. The number you enter here will alter the next figure shown, which is the number of days per year available for farming.

The next question is your average water temperature. This information is used in the growth model. For Lake Victoria a temperature of 26°C is suggested. The value must be between 20 and 30°C.

The final question here asks what weight loss you expect between harvesting the fish and the sale of the fish. For instance, if you harvest a fish, bleed it and then remove the guts for sale, the weight loss will be at least 10%. i.e. a 500 g fish at harvest becomes a 450 g fish at the market. See the earlier section on processing for further discussion on this. This adjustment only affects the calculated value and weight distribution of the fish that are sold and not the fish that are produced.

Setting up the strategies

Go to the sheet "S1-Standard" to set up your standard culture plan. There are just four numbers here that you can change.

Strategy 1: Standard Stocking and Harvest

Input data		
Ave wt. at stocking (g)	40	mono sex
Initial stock density (No./m^3)	75	
Days to harvest | Predicted average weight	137	499g
Temp. (Degrees C)	26	
Cage type	Rectangular	
Cage surface area (m^2)	9.0	
Cage depth (m)	3.0	
Days between harvest and restocking	10	

Figure 47: Setup options on the first strategy page

The first is the average weight of the fry or fingerlings that you stock. The minimum size you can specify is 1 g. The model is not intended to be used for very early rearing. Also, note that the model has only been tested against data from a growth trial from 40 to 500 g, so it may be less accurate for smaller and larger fish. The accuracy will also decline the longer the growth period. You can use the drop-down selection adjacent to the average stock weight figure to specify whether the fish are mono-sex or mixed-sex. This makes no difference to the growth calculations, but different fry prices can be set up which will change the financial analysis slightly.

You should then specify the number of fish you stock per cubic meter of cage volume. If you have not previously calculated this, divide the total number of fish that you stock into a cage by the cage volume which is calculated on the "0-StartHere" sheet.

You are then asked to specify the number of days between stocking and harvesting the fish. If you have a normal number of days then you can enter that here. If you plan to grow the fish to a certain average size, note the average weight figure shown adjacent to the "Days to harvest". As you increase the "Days to harvest" number, the average harvest weight figure will also increase. Adjust the "Days to harvest" number until it predicts your target harvest weight.

This section also shows the average temperature and the cage dimensions which can be adjusted on the "0-StartHere" sheet.

The final data element you can adjust on this page is the days between harvesting and restocking. The spreadsheet first gives you information about a single culture cycle in a cage, but then also extrapolates that to an annual estimate, assuming that you keep repeating the same pattern with just a break for cage maintenance etc. For instance, with a cycle length of 137 days and 10 days for maintenance, you could run 2.5 cycles per year (365/(137+10)=2.6) in each cage.

The remainder of the sheet provides calculated data about each cage cycle and then multiplies this by the cycles per year number to give data for the cage over a full year.

Table 14: Output data for a single cycle

Output data (per cage/cycle)	
Cycle per year	2.48
Cage volume (m^3)	179.0
Number stocked	13,429
Biomass stocked (kg)	537
Ave. harvest weight (g)	499
Harvest number	12,790
Harvest biomass (kg)	6,384
Final stock density (kg/m^3)	35.7
Mortalities (No.)	653
Mortalities (%)	4.9%
Mortality biomass (kg)	64.15
Feed used (kg)	8,850
Biological FCR	1.50
Economic FCR	1.51
Sales income (KES)	2,321,137
Feed cost (KES)	886,254
Fry cost (KES)	537,148
Income less feed and fry (KES)	897,735
% margin on feed and fry cost	38.7%
Including short-term finance cost:	
Interest paid on fry (KES)	28,226
Interest paid on feed (KES)	18,628
Total short-term financing (KES)	46,854
Adjusted Income less fry and feed cost (KES)	850,881
Adjusted % margin on fry and feed cost	36.7%

Table 13: Output data for a calendar year

Output data (per cage/year)	
Annual production (kg)	15,852
Annual income (KES)	5,763,368
Annual feed use (kg)	21,973
Fingerlings used (No.)	33,343
Feed cost (KES)	2,200,563
Fingerling cost (KES)	1,333,735
Income less feed and fry (KES)	2,229,070
Including short-term finance cost:	
Feed cost (KES)	2,246,817
Fingerling cost (KES)	1,403,820
Income less feed and fry (KES)	2,112,731

The summary costs for feed and seed are first shown excluding any consideration of the cost of financing their purchase (e.g. through a short-term credit or overdraft facility). These are also the values shown in the charts. Below these values are the costs including interest payments on short-term credit. This is discussed further in the advanced setup section.

The accompanying charts summarise key information such as the expected growth of the fish and corresponding feed used, the expected distribution of harvested fish by weight category, and a breakdown of major operating cost categories and income.

The first pair of charts (at the top as they are the most important), show the main operational costs (feed and fry) compared with sales income and gross operating margin (i.e. value of sales less fry and feed costs) for a single cage cycle. If sales income exceeds the cost of feed and seed, the first chart shows the cost of fry and feed separately with any margin above these. If the cost of fry and feed exceeds the expected sales income, the operation will make a loss and this is shown by the bar extending below the zero line. The sales income is the sum of fry, feed and income less fry and feed.

The second chart combines fry and feed costs but also shows the three main indicators (sales income, fry and feed cost and surplus/margin) side-by-side for comparison. Again, if there is a loss rather than a surplus, this is shown below the zero line.

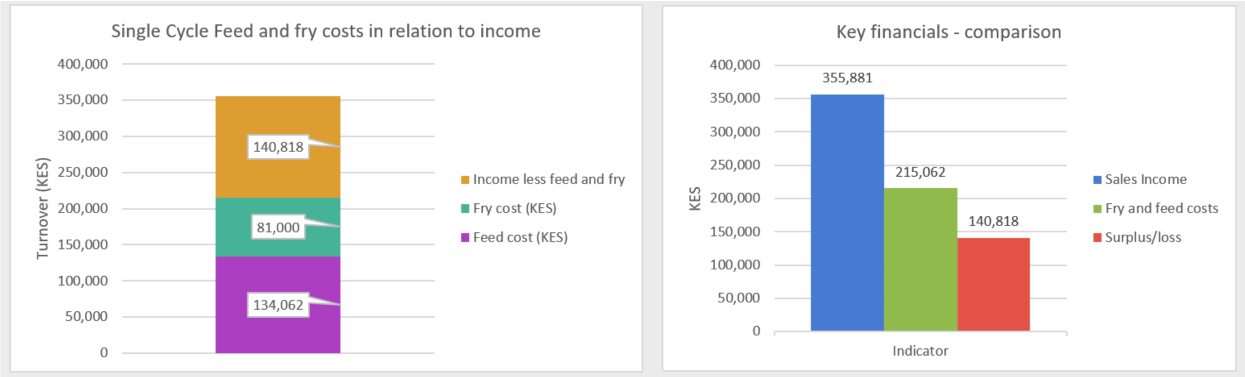


Figure 48: Key financial indicators with positive surplus

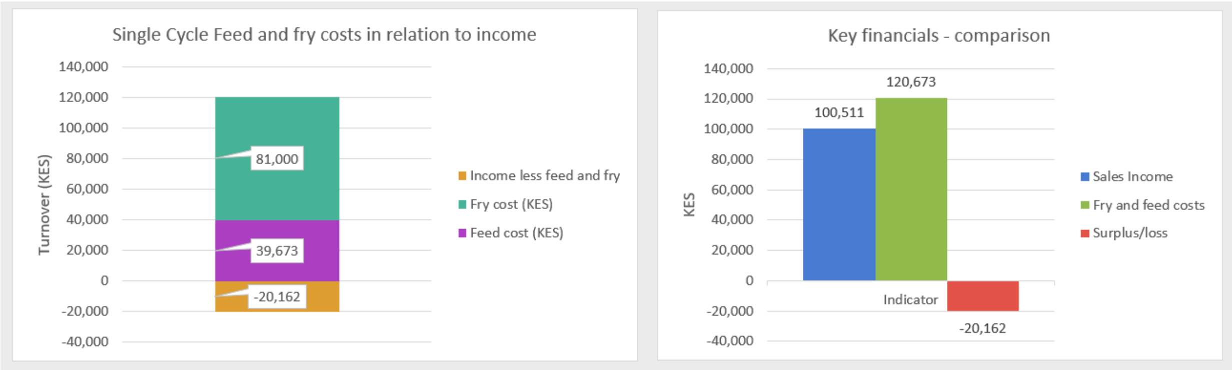


Figure 49: Key financial indicators showing financial loss

Below the summary financial information are the biological performance charts; growth and mortalities.

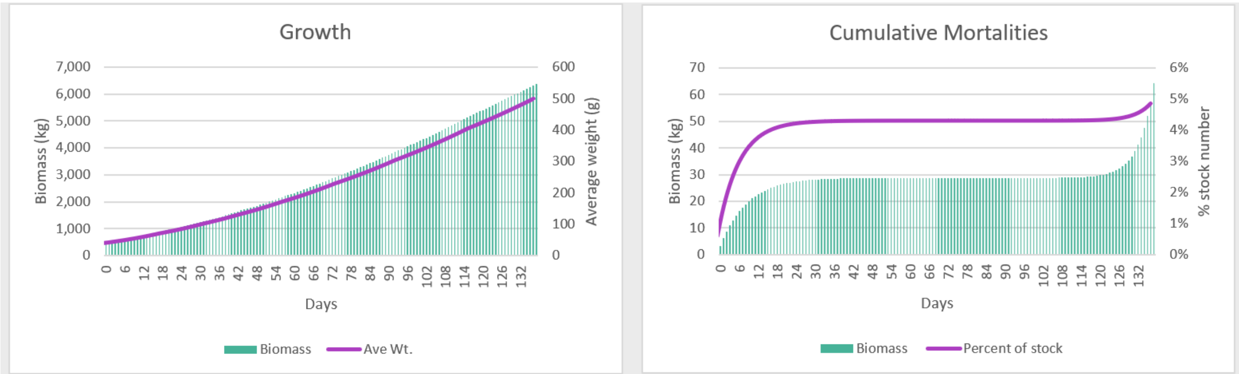


Figure 50: Charts showing daily cumulative growth and mortalities

One of the most critical variables is the price per kg that can be obtained for different sizes of tilapia. In general, larger tilapia are more expensive per kilogram. The next charts show the expected distribution of size grades within the harvest (normal distribution) and the corresponding contribution from the sale of each size grade to total income. The spread of sizes is adjusted in the model by altering the value of the coefficient of variation on the "0-StartHere" sheet.

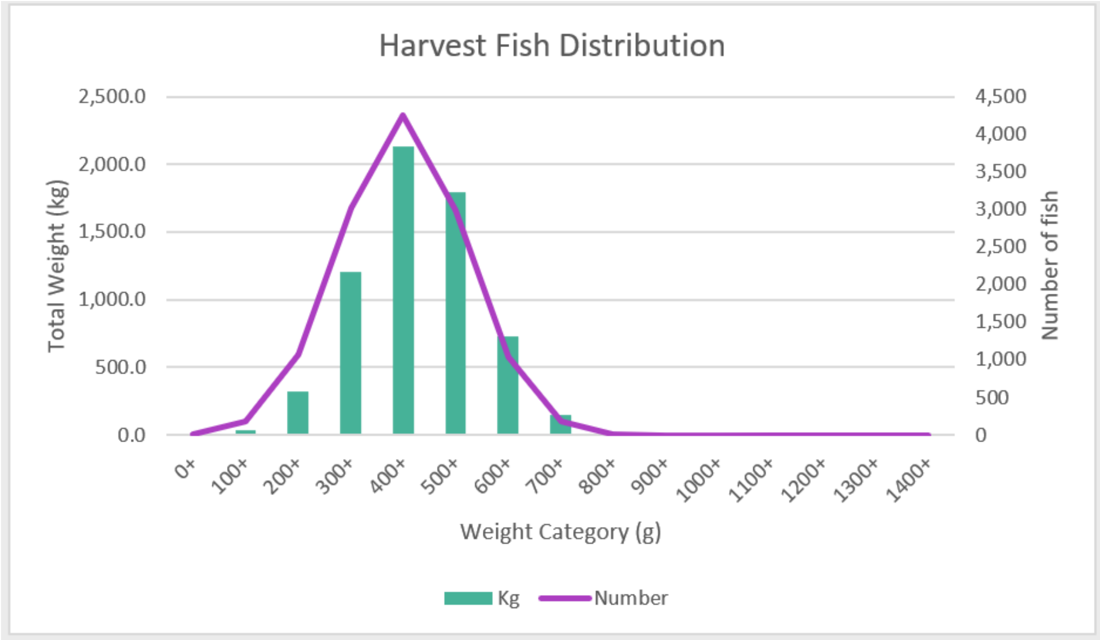


Figure 51: Chart showing estimated distribution of fish by average weight

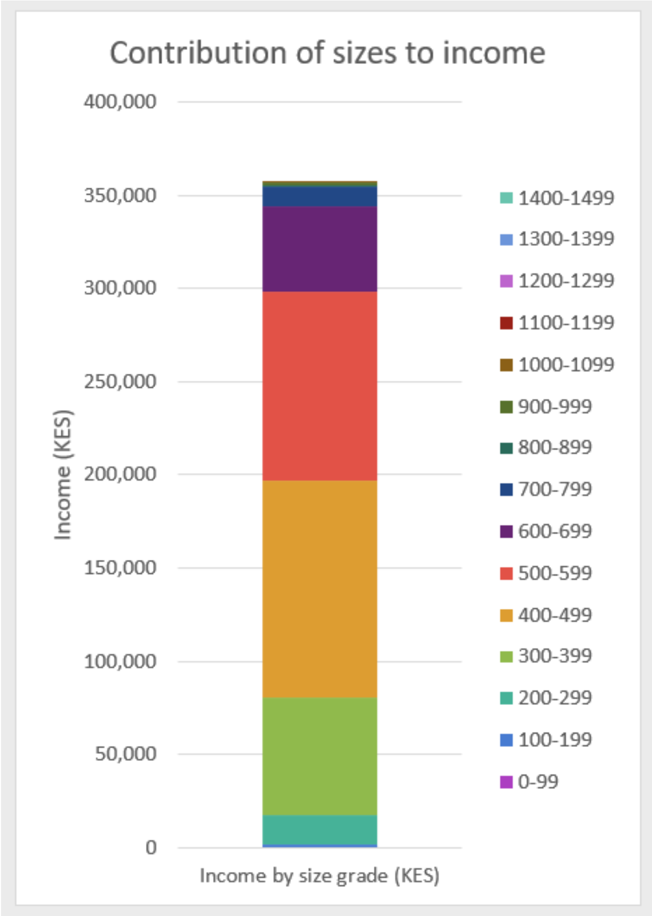


Figure 52: Chart showing contribution of each fish weight category to total income

The final charts show the increasing stock density over the culture cycle (kg/biomass per m[3] of cage volume), and the pattern of feed consumption, with an adjacent table indicating expected quantities by feed type and grade.

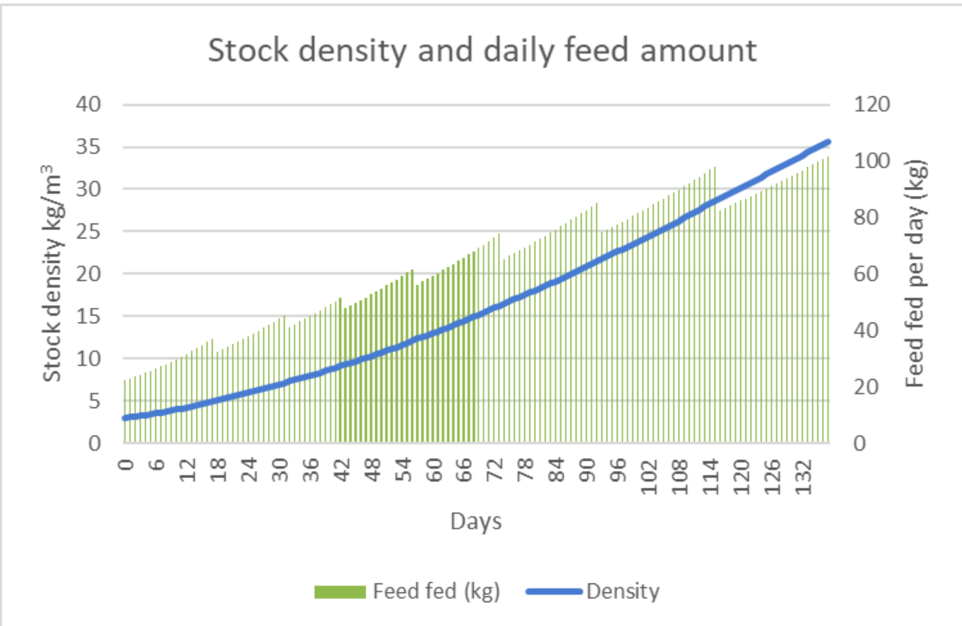


Figure 53: Chart showing increasing daily feed quantities and stock density over production cycle

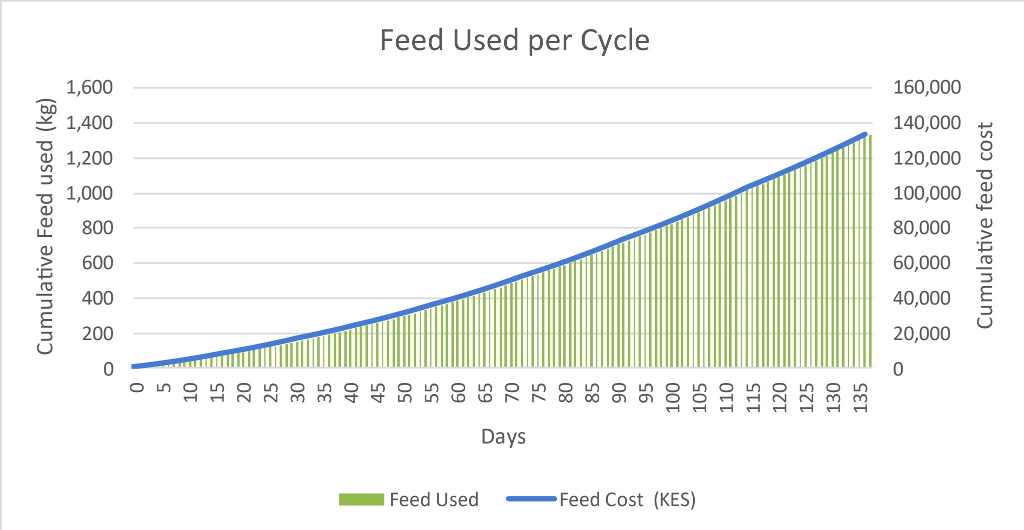
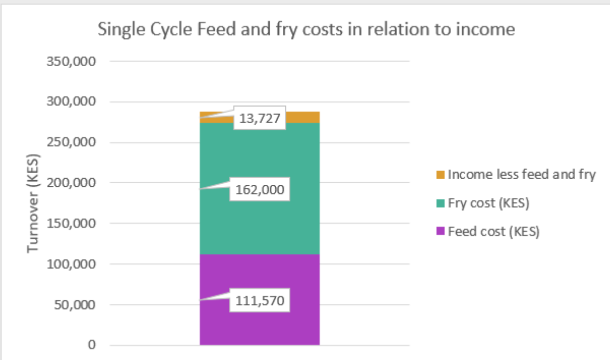


Figure 54: Chart showing cumulative feed use and cost

Table 15: Example table summarising feed use by type

Feed Use by Type	Kg used	Cost (KES)
Skretting 0.5mm	0	0
Skretting 1mm	0	0
Skretting 2mm	0	0
Unga 2mm	0	0
Unga 3mm	154	16,377
Unga 4mm	1,185	117,685

The strategy sheets "S2-Double" and "S3-Short" are in the same format as the first sheet. Taking the S3-Short sheet as an example, the reduced culture time leads to the harvest of smaller fish at lower values, so the margin obtained falls as a percentage of total turnover. However, the risk of serious losses is reduced by shortening the culture cycle, and the fish may be easier to market locally. It also means less financial outlay before income can be realised – i.e. better cash flow.



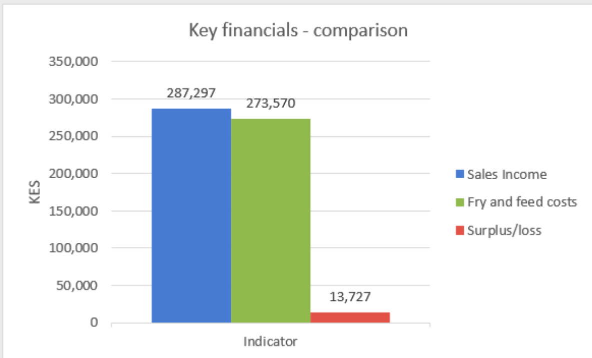


Figure 55: Example financial indicators from a short culture cycle

The final strategy "S4-PartialHarvest" is more complex as it assumes an interim partial harvest of the fish that are initially stocked. For this strategy you need to specify the number of days to the first harvest and what percentage of the fish will be removed at that stage as well as specifying the total culture days.

Strategy 4: Double Stocking with Partial Harvest

Input data		
Ave wt. at stocking (g)	40	mono sex
Initial stock density (No./m^3)	150	
Days to first harvest | Predicted average weight (Interim)	75	234g
% fish removed at first harvest	50%	
Total culture days | Predicted average weight (Final)	137	499g
Temp. (Degrees C)	26	
Cage type	Rectangular	
Cage surface area (m^2)	9.0	
Cage depth (m)	3.0	
Days between 2nd harvest and restocking	10	

Figure 56: Setup options for partial harvest strategy

As with the other strategies, you can directly monitor the predicted average weight for the number of culture days specified. You can also check the calculated data below for maximum stock density. The calculations are divided into sections for the first harvest, the second harvest, the combined harvest, and then the extrapolated annual totals.

Table 16: Example output data for partial harvest strategy

Output data (per cage/cycle)	
Cycle per year	2.48
Cage volume (m^3)	179.0
Number stocked	26,857
Biomass stocked (kg)	1,074
1st harvest	
Ave. 1st harvest weight (g)	234
Stock density at 1st harvest (kg/m^3)	33.07
1st harvest number	12,850
1st harvest biomass (kg)	2,961
Mortalities to 1st harvest (No.)	1247
Mortalities to 1st harvest (%)	4.6%
Mortalities to 1st harvest biomass (kg)	78.56
Feed used to 1st harvest (kg)	7,061
Feed used for 1st harvested fish (kg)	3,531
Biological FCR to 1st harvest	1.80
Economic FCR to 1st harvest	1.87
Feed cost to 1st harvest (KES)	709,283
Cost to feed first harvested fish (KES)	354,641
Sales income 1st harvest (KES)	910,942
1st harvest share of fry cost (KES)	548,414
Income less fry and feed to first harvest	7,887
% margin on feed and fry cost to first harvest	0.9%
2nd harvest	
Ave. final harvest weight (g)	499
Biomass remaining after 1st harvest (kg)	3,004
Stock density after 1st harvest (kg/m^3)	16.78
Final stock density (kg/m^3)	34
Final harvest number	12,322
Final harvest biomass (kg)	6,153
Biomass increase between 1st & 2nd harvests (kg)	3,149
Mortalities between 1st & 2nd harvests	465
Mortality biomass between 1st & 2nd harvests (kg)	150.0
Feed used for 2nd harvest fish (kg)	8,654
Feed used between 1st and 2nd harvests (kg)	5,124
Biological FCR 1st to 2nd harvest	1.55
Economic FCR 1st to 2nd harvest	1.63
Feed cost for 2nd harvest fish (KES)	870,166
Sales income from 2nd harvest (KES)	2,237,067
Final harvest share of fry/fingerling cost (KES)	525,882
Income less fry and feed from first to final harvest	841,020
% margin on feed and fry cost from 1st to final harvest	37.6%

Totals	
Total number (survived)	25,173
Total mortalities	1,712
Total mortalities %	6.4%
Total mortalities biomass (kg)	228.6
Total harvest (kg)	9,113
Total feed used (kg)	12,185
Overall biological FCR	1.47
Overall economic FCR	1.52
Total feed cost (KES)	1,224,807
Fry/Fingerling cost (KES)	1,074,296
Sales income (KES)	3,148,009
Income less feed and fry (KES)	848,906
% margin on feed and fry cost	27.0%
Including short-term finance cost:	
1st Harvest	
Interest paid on fry (KES)	15,776
Interest paid on feed (KES)	4,081
2nd Harvest	
Interest paid on fry (KES)	27,634
Interest paid on feed (KES)	18,290
Totals	
Total short-term financing (KES)	65,781
Adjusted Income less fry and feed cost (KES)	783,125
Adjusted % margin on fry and feed cost	24.9%
Output data (per cage/year)	
Annual production (kg)	22,628
Annual income (KES)	7,816,485
Annual feed use (kg)	30,256
Fingerlings used (No.)	66,687
Feed cost (KES)	3,041,187
Fingerling cost (KES)	2,667,469
Income less feed and fry (KES)	2,107,829
Including short-term finance cost:	
Feed cost (KES)	3,096,734
Fingerling cost (KES)	2,775,257
Income less feed and fry (KES)	1,944,494

The growth chart shows the continued increase in average weight, but a substantial drop in biomass when the first fish are harvested. In addition to contributing to cashflow, this early harvest also prevents the stock density from increasing beyond reasonable limits.

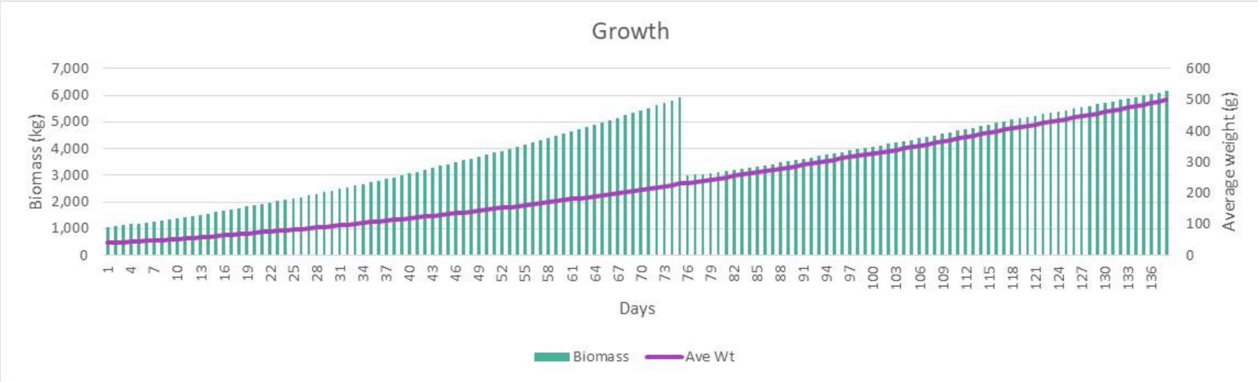


Figure 57: Chart showing development of fish weight and biomass with partial harvest

The cumulative mortality chart now shows the additional mortalities following the interim harvest.

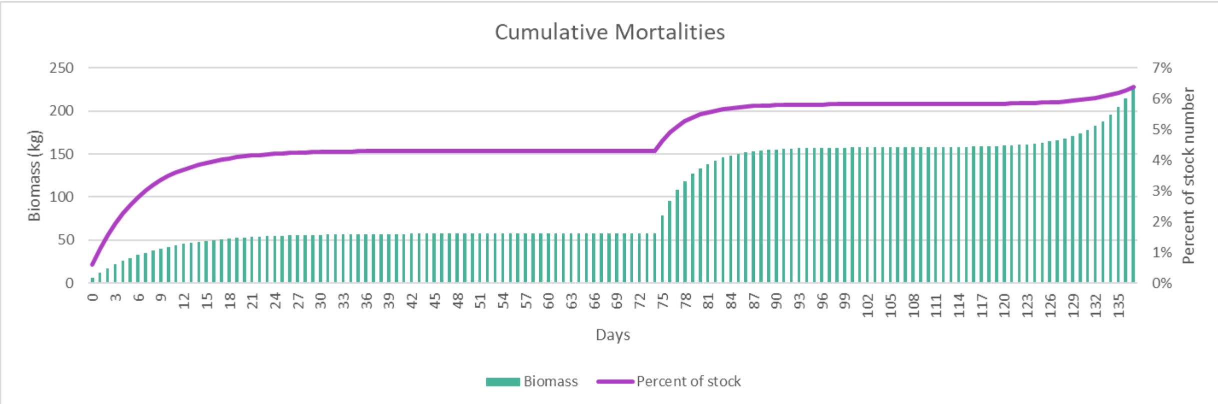


Figure 58: Chart showing cumulative mortalities with rise after partial harvest

The size at harvest chart is now bi-modal reflecting the combination of the two harvests. Separate charts are available on the Growth-Model-4 sheet.

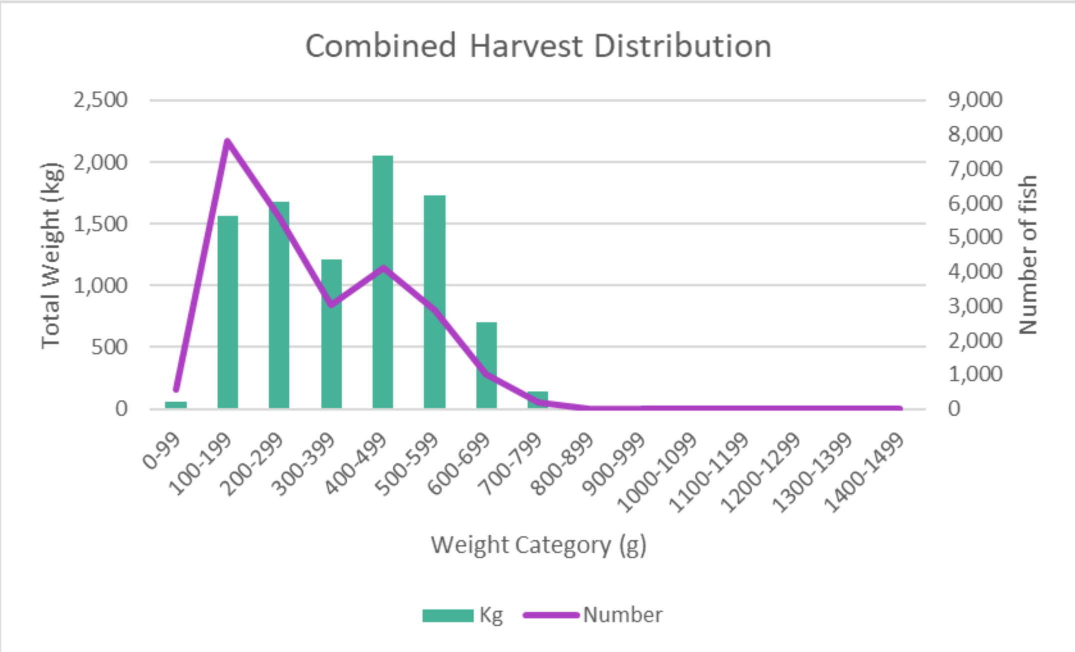


Figure 59: Chart showing expected distribution of harvest weights for combined first and second harvests

The financial charts show the results for combined first and second harvest, and then separate charts for the first and second harvest.

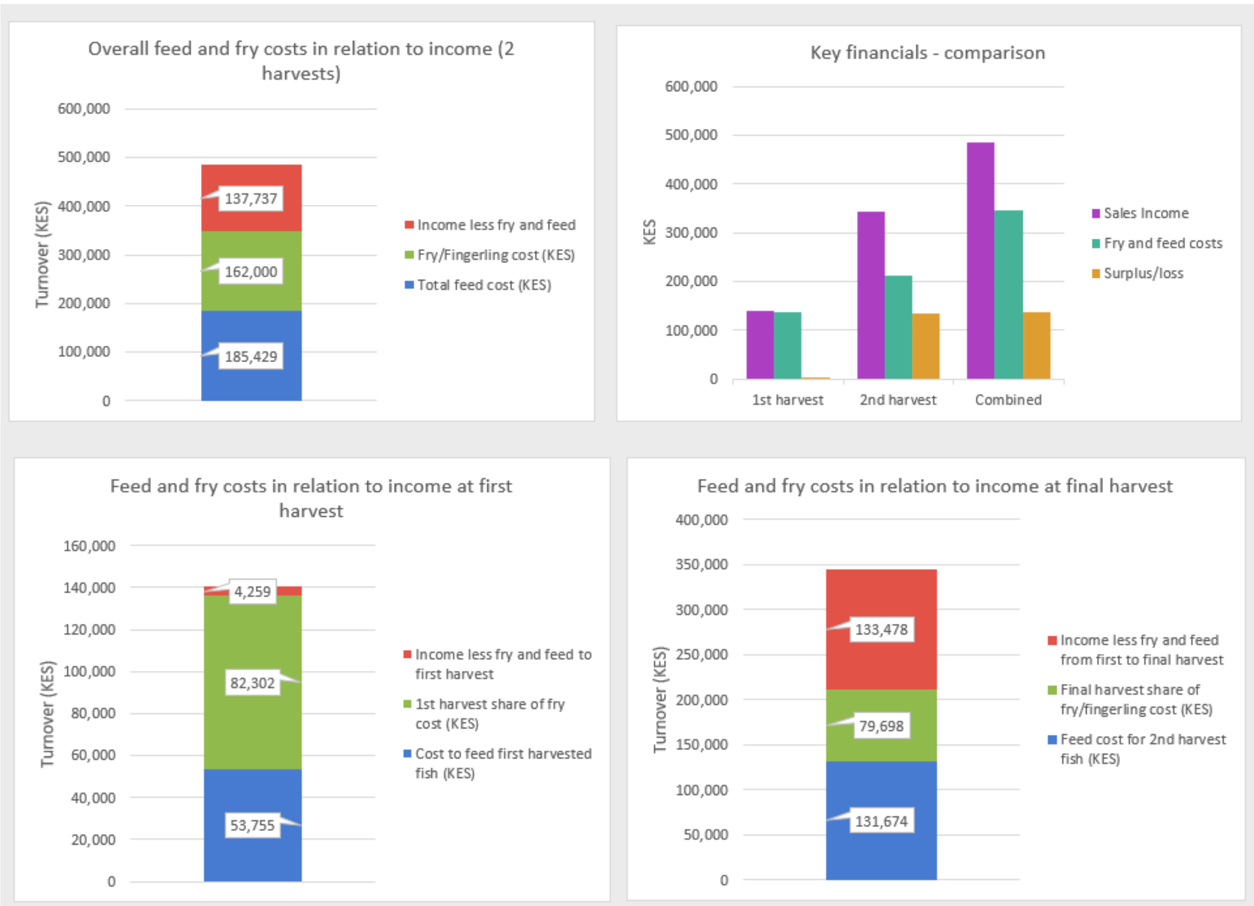


Figure 60: Key indicator charts for partial harvest strategy

Comparing and combining strategies

Once you have experimented with different strategies for your cages, you can compare them on the sheet "5-Comparison". The first section summarises and compares the key annual results from the four previous strategy sheets.

Table 17: Summary table comparing results of 4 strategies

Annual comparison for 1 cage

	Strategy 1	**Strategy 2**	**Strategy 3**	**Strategy 4**
	Standard	Double	Short	Partial
Annual production (kg)	15,852	29,927	25,753	22,628
Annual income (KES)	5,763,368	10,820,795	7,878,272	7,816,485
Annual feed use (kg)	21,973	43,523	30,809	30,256
Fingerlings used (No.)	33,343	66,687	113,988	66,687
Feed cost (KES)	2,246,817	4,450,716	3,157,980	3,096,734
Fry/Fingerling cost (KES)	1,403,820	2,807,639	4,692,424	2,775,257
Income less feed and fry (KES)	2,112,731	3,562,439	27,868	1,944,494

Include the cost of short term credit for fry and feed?
yes

The table above summarises the results for each of the 4 strategies.
You can now allocate your cages to the stragegies for a total annual production estimate

For these calculations, you can decide whether to include or exclude short-term interest payments on fry and feed purchases via a yes/no dropdown.

Figure 61: Chart comparing key financial data between strategies

From this information, you can pick out which strategy provides the greatest income, but also which provides the best margin or the lowest feed cost for instance.

The next step is to allocate your cages (or cage groups) to the chosen strategies. If you wish, you can allocate them all to one strategy, or you can choose a mix. When the number of cages you have allocated in the white cells adds up to the number of cages specified on the "0-StartHere" page, you will get a green "OK" adjacent to the allocation row. The data below multiplies the annual per-cage data by the number of cages to give a total for all cages, together with some analysis of the contribution of each strategy to the total production and earnings.

Annual total for all cages

Number of cages to allocate (from start page): 8

	Strategy 1	Strategy 2	Strategy 3	Strategy 4		
	Standard	Double	Short	Partial		
Number of cages per strategy	1	4	0	3	8	OK
						TOTAL
Cage volume (m^3)	27	108	0	81		216
Percentage of total cage volume	13%	50%	0%	38%		100%
Annual production (kg)	2,390	18,052	0	10,237		30,679
Percentage of total production	8%	59%	0%	33%		100%
Annual income (KES)	774,522	5,817,442	0	3,112,621		9,704,585
Percentage of annual income	8%	60%	0%	32%		100%
Annual feed use (kg)	3,313	26,253	0	13,687		43,253
Fingerlings used (No.)	5,028	40,224	0	30,168		75,421
Feed cost (KES)	338,812	2,684,609	0	1,400,930		4,424,350
Fry/Fingerling cost (KES)	211,691	1,693,528	0	1,255,497		3,160,716
Income less feed and fry (KES)	224,019	1,439,305	0	456,195		2,119,519
Percentage of income less feed and fry	11%	68%	0%	22%		100%

Figure 62: Setup and preliminary analysis section for combined strategy

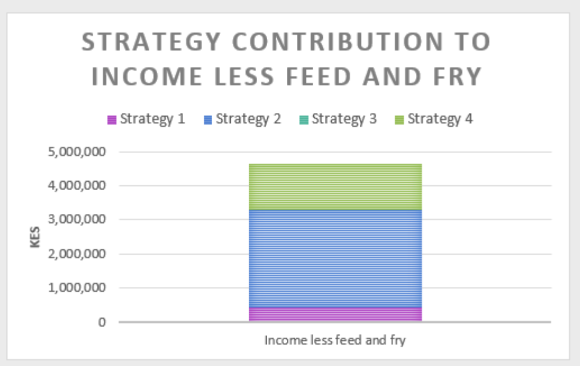


Figure 63: Chart summarising contribution of each strategy to income less feed and fry

A chart adjacent to this table helps to visualise the contribution each cage strategy makes to your overall gross income. In this example, strategy 2 provides the greatest income, followed by strategy 4 and then 1.

The remainder of this page summarises further financial analysis. This is discussed in the following section as it is necessary to add more farm-specific information before the results will be helpful.

Advanced set-up and analysis

Introduction

Once you are familiar with the basic operation of this spreadsheet, you are likely to want to modify some values to better suit your conditions and operations, and to update cost and price information. In this section, we go through how to do this and the options available.

The Growth Model Sheets

Firstly, note that there is more detailed information available about each strategy in the sheets “Growth-Model-1” to “Growth-Model-4”. These contain the detailed growth models for each strategy, showing the feed fed and growth increment for each day as well as changes in numbers due to mortalities. These sheets take inputs from the strategy set-up sheets, and also from the data tables that follow the growth models. There is no data to edit on the growth model sheets. It can however be useful to check daily predictions with actual farm data.

Table 18: Partial example of detailed data tables in the Growth Model sheets

Day	Av. Wt (g)	Feed rate % bw/day	FCR	SGR	No.	Early Morts	Late Morts	Cum. Morts	Cum Mort %	Mort Biomas (g)	Cum. Mort biomass (kg)	Biomass (kg)	Density (kg/m3)	Feed fed (kg)
0	40.00	4.17	1.28	3.25	2025	12.15	0.00	12.15	0.60%	486	0.486	81.00	3.00	3.38
1	41.32	4.17	1.28	3.25	2,012.85	10.46	0.00	22.61	1.12%	432	0.918	83.17	3.08	3.47
2	42.68	4.17	1.28	3.25	2,002.39	9.00	0.00	31.61	1.56%	384	1.302	85.47	3.17	3.56
3	44.09	4.17	1.28	3.25	1,993.39	7.75	0.00	39.36	1.94%	342	1.644	87.90	3.26	3.66
4	45.55	4.17	1.28	3.25	1,985.64	6.67	0.00	46.02	2.27%	304	1.948	90.45	3.35	3.77
5	47.05	4.17	1.28	3.25	1,978.98	5.74	0.00	51.76	2.56%	270	2.218	93.12	3.45	3.88
6	48.61	4.17	1.28	3.25	1,973.24	4.94	0.00	56.70	2.80%	240	2.458	95.91	3.55	4.00
7	50.21	4.17	1.28	3.25	1,968.30	4.25	0.00	60.95	3.01%	213	2.671	98.83	3.66	4.12
8	51.87	4.17	1.28	3.25	1,964.05	3.66	0.00	64.61	3.19%	190	2.861	101.87	3.77	4.25
9	53.58	4.17	1.28	3.25	1,960.39	3.15	0.00	67.76	3.35%	169	3.030	105.04	3.89	4.38
10	55.35	4.17	1.28	3.25	1,957.24	2.71	0.00	70.47	3.48%	150	3.180	108.34	4.01	4.52
11	57.18	4.17	1.28	3.25	1,954.53	2.33	0.00	72.81	3.60%	133	3.313	111.76	4.14	4.66
12	59.07	4.17	1.28	3.25	1,952.19	2.01	0.00	74.82	3.69%	119	3.432	115.31	4.27	4.81
13	61.02	4.17	1.28	3.25	1,950.18	1.73	0.00	76.55	3.78%	105	3.537	118.99	4.41	4.96
14	63.03	4.17	1.28	3.25	1,948.45	1.49	0.00	78.03	3.85%	94	3.631	122.81	4.55	5.12
15	65.11	4.17	1.28	3.25	1,946.97	1.28	0.00	79.31	3.92%	83	3.715	126.77	4.70	5.28
16	67.26	4.17	1.28	3.25	1,945.69	1.10	0.00	80.42	3.97%	74	3.789	130.87	4.85	5.46
17	69.48	4.17	1.28	3.25	1,944.58	0.95	0.00	81.36	4.02%	66	3.855	135.11	5.00	5.63
18	71.78	3.54	1.35	2.62	1,943.64	0.82	0.00	82.18	4.06%	59	3.913	139.51	5.17	4.94
19	73.68	3.54	1.35	2.62	1,942.82	0.70	0.00	82.88	4.09%	52	3.965	143.15	5.30	5.07
20	75.63	3.54	1.35	2.62	1,942.12	0.60	0.00	83.49	4.12%	46	4.011	146.89	5.44	5.20
21	77.64	3.54	1.35	2.62	1,941.51	0.52	0.00	84.01	4.15%	40	4.051	150.74	5.58	5.34
22	79.70	3.54	1.35	2.62	1,940.99	0.45	0.00	84.46	4.17%	36	4.087	154.69	5.73	5.48
23	81.81	3.54	1.35	2.62	1,940.54	0.39	0.00	84.84	4.19%	32	4.119	158.76	5.88	5.62
24	83.98	3.54	1.35	2.62	1,940.16	0.33	0.00	85.18	4.21%	28	4.146	162.94	6.03	5.77
25	86.21	3.54	1.35	2.62	1,939.82	0.29	0.00	85.46	4.22%	25	4.171	167.23	6.19	5.92

Below the daily data is the table that analyses the size distribution of the harvested fish.

This starts with a summary of the harvest data and the CV value and harvest weight adjustment figure from the “0-StartHere” page.

Table 19: Example harvest data used to generate size distribution table

Harvest summary		Before weight loss
Fish Number	12,790	
Avg. wt. (g)	449	499
cv	24%	
SD	107.8219	
Biomass (kg)	5,746	
Weight loss adjusment		
% of harvest wt.	*90%*	

The biomass is then split between the size grades in the adjacent table and price data is applied from the "SalesPrices" sheet (see later) to calculate the income by size group.

Table 20: Generated table of fish size distribution

Wt class	KES/kg	Prob.	Number	Kg	% No.	% Biomass	Cum. No.	Cum. Bion	Income by size grade (KES)
100	219	0.19%	25	2.5	0.19%	0.04%	0.19%	0.04%	545.87
200	271	2.56%	327	65.4	2.56%	1.14%	2.75%	1.18%	17,724.67
300	344	14.19%	1,815	544.6	14.19%	9.48%	16.95%	10.66%	187,337.02
400	358	33.33%	4,263	1,705.3	33.34%	29.68%	50.28%	40.34%	610,496.48
500	365	33.12%	4,236	2,118.1	33.12%	36.86%	83.41%	77.20%	773,090.85
600	363	13.92%	1,781	1,068.5	13.93%	18.60%	97.33%	95.80%	387,868.35
700	378	2.48%	317	221.7	2.48%	3.86%	99.81%	99.66%	83,812.04
800	388	0.19%	24	19.1	0.19%	0.33%	99.99%	99.99%	7,398.77
900	405	0.01%	1	0.7	0.01%	0.01%	100.00%	100.00%	276.62
1000	405	0.00%	0	0.0	0.00%	0.00%	100.00%	100.00%	4.14
1100	405	0.00%	0	0.0	0.00%	0.00%	100.00%	100.00%	0.03
1200	405	0.00%	0	0.0	0.00%	0.00%	100.00%	100.00%	0.00
1300	405	0.00%	0	0.0	0.00%	0.00%	100.00%	100.00%	0.00
1400	405	0.00%	0	0.0	0.00%	0.00%	100.00%	100.00%	0.00
1500	405	0.00%	0	0.0	0.00%	0.00%	100.00%	100.00%	0.00
		100%	12,789	5,745.8	100.0%	100.0%			2,068,555

The Advanced Setup Menu

To get started with a more advanced setup, return to the "0-StartHere" page and scroll down to the advanced setup section. In this section, there are a series of buttons that take you to data input tables and some values that you can input directly on this page.

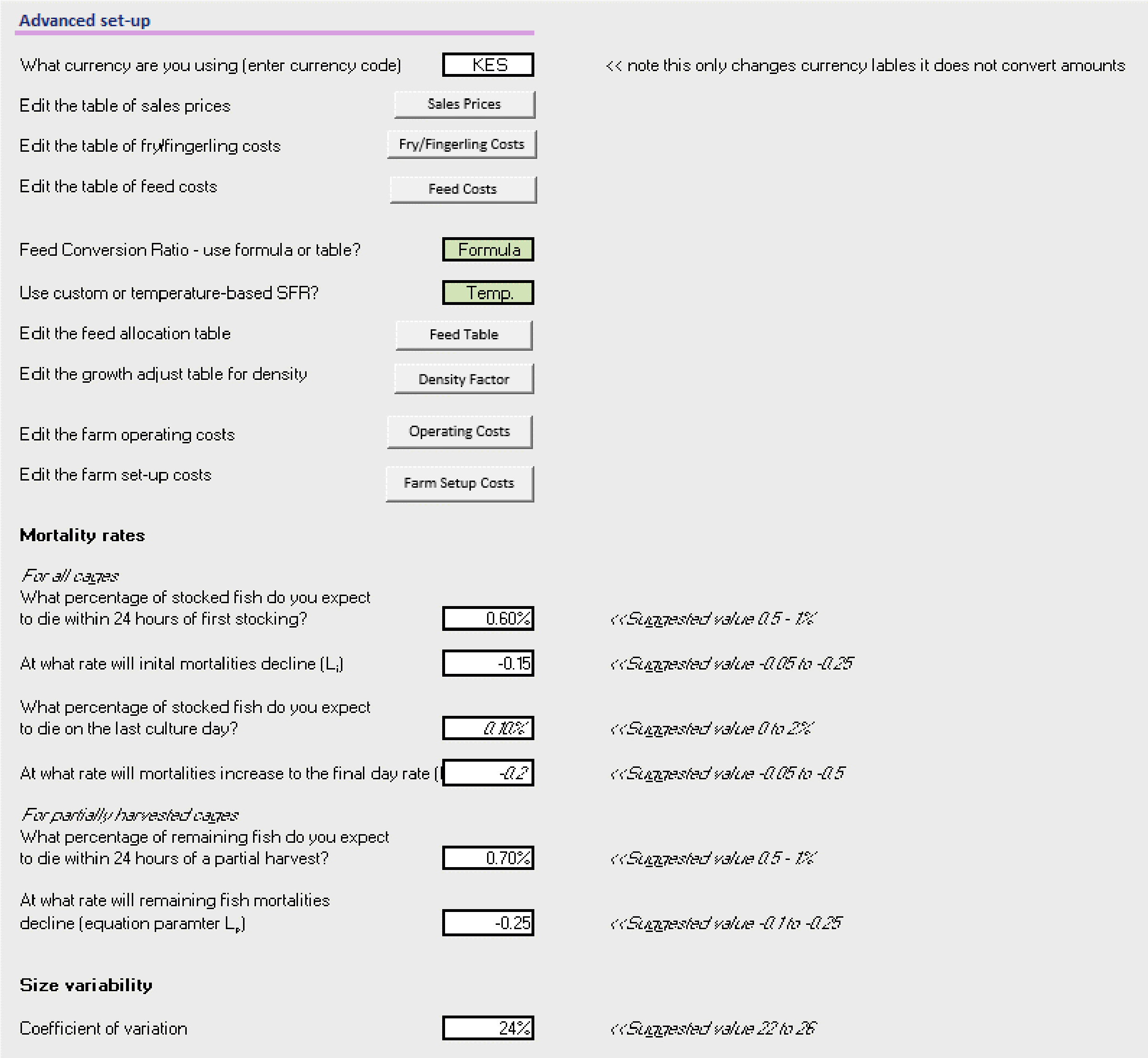


Figure 64: Advanced setup section on the start page

We will work through these in turn. However, please note also that if you wish to change the titles for any of the scenarios (e.g. you wish to use the "Double" sheet to consider a different growth cycle duration), you can do so via fields at the end of this sheet. There is a full title and a short title. The short title is used on the "5-Comparison" page where more compact headings are required.

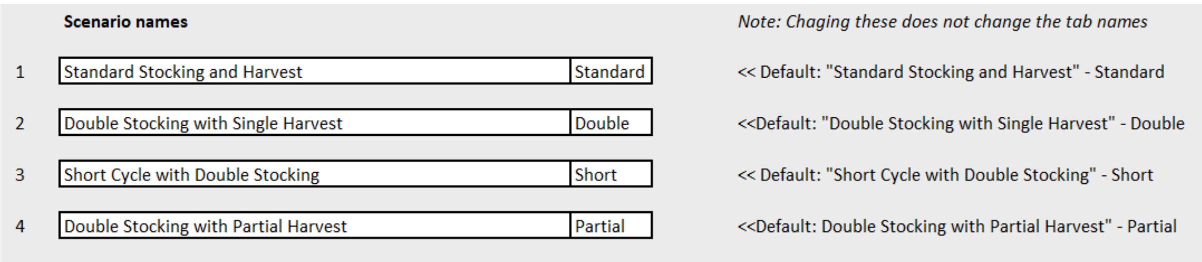


Figure 65: Setup section for scenario names

Currency

The first item you can change in the advanced set-up section is the currency symbol or code that is shown. The default is "KES" (Kenyan Shillings), but you can change this to Ksh, or to any other currency code (e.g. TZS (Tanzanian Shillings), UGX or USh (Ugandan Shilling), or RWF (Rwandan Franc) etc. However, please note this only changes the symbols shown in the tables and charts, it does not perform any currency conversion, so you must ensure all price and cost data is updated if you decide to use a different currency.

Sales Prices

Click on the button "Sales Prices" to go to the corresponding datasheet. You will see a data table showing size ranges (in 100g increments) and a corresponding price per kilogram. Edit the price per kilogram according to your knowledge of the market. Note that if these prices are for gutted fish, for instance, you should adjust the yield (loss of weight between harvest and sales) figure in the initial setup to match.

Table 21: Setup table for sales prices

Size Range (g)	Label	Wt class	KES/kg
0-99	0+	100	219
100-199	100+	200	271
200-299	200+	300	344
300-399	300+	400	358
400-499	400+	500	365
500-599	500+	600	363
600-699	600+	700	378
700-799	700+	800	388
800-899	800+	900	405
900-999	900+	1000	405
1000-1099	1000+	1100	405
1100-1199	1100+	1200	405
1200-1299	1200+	1300	405
1300-1399	1300+	1400	405
1400-1499	1400+	1500	405

Once you have edited this table, you can use the adjacent button to return to the initial setup page.

Fry/Fingerling Costs

Click on the button "Fry/Fingerling Costs" to go to the table to set these up. You can provide separate prices for mono-sex and mixed-sex fry if applicable (choice is made on the scenario set-up pages).

Table 22: Setup table for fry cost

Wt (g)	mono sex	mixed sex
1	2	1
3	4	2
5	6	3
10	12	6
20	20	10
30	30	15
40	40	20
50	50	25
60	60	30

This is a lookup table where the lower price will be used until the next weight is reached. i.e. when setting up the strategy sheets you select a fingerling size of 25g the price selected from this table for a mono-sex fingerling would be 20 KES (i.e. the price for 20g fingerlings would apply).

You can change the values in both the weight column and the cost columns, but you must ensure that the weights are in ascending order as shown.

Feed Costs

The feed cost table can be reached in the same way by clicking on the appropriate button on the initial setup page. You should edit this table to show the feeds that you expect to use. The specifications can usually be obtained from the feed suppliers.

Table 23: Setup table for feed type and cost

Feed	Code	Feed size (mm)	Type	Price KES/kg	Fish weight (g)	Feed rate (Guide-Not Used)	Protein
Skretting 0.5mm	SKN05	0.5	Crumble	**135.58**	1	8%	48%
Skretting 1mm	SKN10	1	Micropellet	**135.58**	3	7%	46%
Skretting 2mm	SKN20	2	Micropellet	**135.58**	7	5%	40%
Unga 2mm	UNG20	2	Pellet	**118.42**	12	5%	35%
Unga 3mm	UNG30	3	Pellet	**106.15**	40	3%	32%
Unga 4mm	UNG40	4	Pellet	**99.33**	100	3%	32%

The feed rate and protein inclusion are not used in the model but can be filled in for reference and comparison. The key column in this table is the fish weight. This is the minimum size in grammes for which that feed can be used. The table must be ordered so that the fish weight values increase from top to bottom as shown above.

Feed Conversion Ratio

The feed conversion ratio (FCR) is used to calculate how much the fish grow based on how much feed they are fed. These conversion rates can be specified using of a mathematical (natural log) formula, or using data directly from trials. The formula defines a relationship between fish weight and feed conversion ratio, such that as fish become larger, the feed conversion ratio also increases (i.e. more feed is needed to achieve the same increment in growth). See the section on feeds and feeding for further explanation.

The choice between using a formula or specifying values directly in a table is selected on the "0-StartHere" sheet using a drop-down selector.

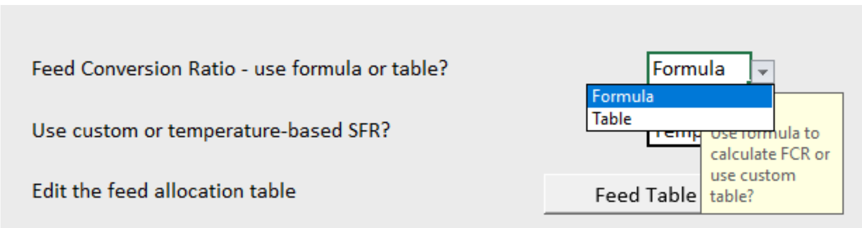


Figure 66: Selecting whether to use table or formula values for FCR

The parameters for the FCR formula are set on the "FeedTables" sheet. The formula is:

$$FCR = a \times \ln(wt) + b$$

Using data from Skretting, suggested values for a and b are:

a (23-25 degrees = 0.0677, 26-28 degrees = 0.0915, 29-30 degrees = 0.8371

b (23-25 degrees = 0.6374, 26-28 degrees = 0.8222, 29-30 degrees = 0.8054)

However, you can adjust these values to fit your data where that is available. Alternatively, you can select “Table” on the “0-StartHere” sheet and enter values directly into the feed table on the “Custom FCR” row (see below).

Specific Feed Rate

The Specific Feed Rate (SFR) is the amount of feed fed per day expressed as a percentage of the fish weight or biomass. Feed manufacturers provide feed tables to show how much to feed at different fish sizes and temperatures. In practice, these are only a guide (see feeds section) but can be used to provide a growth model on the basis that the amount of food fed divided by the food conversion rate gives the growth increment of the fish. The feed table used in this spreadsheet is based on a logarithmic equation:

SFR = a x In(wt) + b

Suggested values for “a” and “b” based on two sets of data at 26°C are:

1. a = -1.089 and b = 9.2748
2. a = -1.12 and b = 8.3

These values can be adjusted on the “FeedTables” sheet.

Alternatively, you can directly enter your own SFR values into the feed table. You need to indicate this on the “0-StartHere” sheet by selecting “Custom” rather than “Temp” in the drop-down selector.

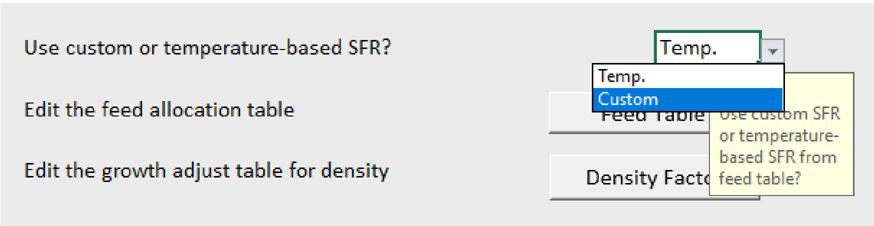


Figure 67: Selecting the method for entering SFR values

Feed Table

The “Feed Table” button on the “0-StartHere” sheet takes you to the “FeedTables” sheet where you can adjust the parameters as indicated above.

The sheet starts with the equations for SFR and FCR.

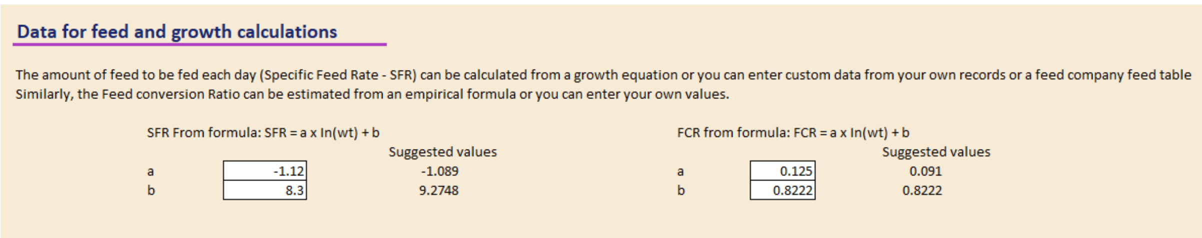


Figure 68: Parameter setup for SFR and FCR

The choices made on the “0-StartHere” sheet are shown below the main feed table. The default values are to use the feed table calculated from the formula to give the SFR value and to use the FCR formula to calculate the FCR. In this case, the SFR value shows the site temperature that will be used which was set on the “0-StartHere” page.

Calculation methods are selected on start page:	
SFR (Temp/Custom):	**26**
FCR (Formula/Custom):	**Formula**

Figure 69: Calculation methods display when using formulas

If you decide to enter your data directly into the feed table, then your choices will show as follows:

Calculation methods are selected on start page:	
SFR (Temp/Custom):	**Custom SFR**
FCR (Formula/Custom):	**Table**

Figure 70: Calculation methods display when using custom values

Now let’s look at the main feed table:

Table 24: The entire feed table

Main Feed Table

% body weight feed per day

You can adjust the values in white boxes in this table, but Fish weight numbers must be in increasing order from left to right

	Fish weight (g)																	
Temp (°C)	1	3	7	12	20	40	70	100	130	170	230	300	400	500	600	700	800	900
20	3.32	2.83	2.45	2.21	1.98	1.67	1.42	1.26	1.14	1.02	0.88	0.76	0.64	0.54	0.45	0.39	0.33	0.27
21	4.15	3.53	3.06	2.76	2.47	2.08	1.77	1.57	1.42	1.27	1.10	0.96	0.79	0.67	0.57	0.48	0.41	0.34
22	4.98	4.24	3.67	3.31	2.97	2.50	2.13	1.89	1.71	1.53	1.33	1.15	0.95	0.80	0.68	0.58	0.49	0.41
23	5.81	4.95	4.28	3.86	3.46	2.92	2.48	2.20	1.99	1.78	1.55	1.34	1.11	0.94	0.79	0.67	0.57	0.48
24	6.64	5.66	4.90	4.41	3.96	3.33	2.83	2.51	2.28	2.04	1.77	1.53	1.27	1.07	0.91	0.77	0.65	0.55
25	7.47	6.36	5.51	4.97	4.45	3.75	3.19	2.83	2.56	2.29	1.99	1.72	1.43	1.21	1.02	0.87	0.73	0.61
26	8.30	7.07	6.12	5.52	4.94	4.17	3.54	3.14	2.85	2.55	2.21	1.91	1.59	1.34	1.14	0.96	0.81	0.68
27	8.30	7.07	6.12	5.52	4.94	4.17	3.54	3.14	2.85	2.55	2.21	1.91	1.59	1.34	1.14	0.96	0.81	0.68
28	7.89	6.72	5.81	5.24	4.70	3.96	3.36	2.99	2.71	2.42	2.10	1.82	1.51	1.27	1.08	0.91	0.77	0.65
29	7.47	6.36	5.51	4.97	4.45	3.75	3.19	2.83	2.56	2.29	1.99	1.72	1.43	1.21	1.02	0.87	0.73	0.61
30	6.64	5.66	4.90	4.41	3.96	3.33	2.83	2.51	2.28	2.04	1.77	1.53	1.27	1.07	0.91	0.77	0.65	0.55
Custom SFR	8.3	7.01	7.6	7.4	7.1	5.5	3.7	2.9	2.6	2.48	2.2	2.09	1.8	1.7	1.6	1.5	1.40	1.30
Custom FCR	0.82	0.96	1.06	1.13	1.2	1.28	1.35	1.4	1.43	1.46	1.5	1.54	1.57	1.6	1.62	1.64	1.66	1.50
Feed Type	Skretting 0.5r	Skretting 1mn	Skretting 2mr	Unga 2mm	Unga 2mm	Unga 3mm	Unga 3mm	Unga 4mm	Unga 4mm	Unga 4mm	Unga 4mm	Unga 4mm	Unga 4mm	Unga 4mm	Unga 4mm	Unga 4mm	Unga 4mm	Unga 4mm
Feed Size	0.50	1.00	2.00	2.00	2.00	3.00	3.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00

As this is difficult to read, the next table shows just the first four fish weights of the above table.

Table 25: Feed Table (First four fish weights)

Main Feed Table

	% body weight feed per day Fish weight (g)			
Temp (°C)	1	3	7	12
20	3.32	2.83	2.45	2.21
21	4.15	3.53	3.06	2.76
22	4.98	4.24	3.67	3.31
23	5.81	4.95	4.28	3.86
24	6.64	5.66	4.90	4.41
25	7.47	6.36	5.51	4.97
26	8.30	7.07	6.12	5.52
27	8.30	7.07	6.12	5.52
28	7.89	6.72	5.81	5.24
29	7.47	6.36	5.51	4.97
30	6.64	5.66	4.90	4.41
Custom SFR	8.3	7.01	7.6	7.4
Custom FCR	0.82	0.96	1.06	1.13
Feed Type	Skretting 0.5	Skretting 1mn	Skretting 2mı	Unga 2mm
Feed Size	0.50	1.00	2.00	2.00

The principle of a feed table was introduced in the feeds section. The table shows the recommended specific feed rate (SFR) at a combination of water temperatures and fish weights. In this table, the values in the 26-degree row are calculated from the SFR equation above. You can change the fish weight values in the top row to match the types of feed that you use. However, the values must be in ascending order from left to right. The Feed Type and Feed Size information is taken from the “FeedCosts” table described earlier.

If you have selected to directly enter your own SFR and/or FCR values, then these should be entered in the rows labelled “Custom SFR” and “Custom FCR”.

If you are using the feed table generated from the equation, the SFR for each fish weight is adjusted for temperature using a second adjustment table which can be found to the right of the main feed table.

Table 26: Table to adjust feed rate for temperature

Feed adjustment table for temperature

	1	3	7	12	20	40	70	100	130	170	230	300	400	500	600	700	800	900
20	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
21	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
22	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%
23	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
24	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
25	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
26	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
27	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
28	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%	95%
29	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
30	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%

The default values for 26°C are also used for 27°C. The feed rate is adjusted downwards at both higher and lower temperatures by multiplying by an adjustment percentage. You can edit these values to change any value on the main feed table.

The actual data used in the growth calculations are then shown in the Growth Table.

Table 27: The growth table

Growth Table	*(data used in model calculations)*												
BW (g)	1	3	7	12	20	40	70	100	130	170	230	300	400
BW (kg)	0.001	0.003	0.007	0.012	0.02	0.04	0.07	0.1	0.13	0.17	0.23	0.3	0.4
SFR (% bm/d)	8.30	7.07	6.12	5.52	4.94	4.17	3.54	3.14	2.85	2.55	2.21	1.91	1.59
FCR	0.82	0.96	1.07	1.13	1.20	1.28	1.35	1.40	1.43	1.46	1.50	1.54	1.57
SGR	10.09	7.37	5.74	4.87	4.13	3.25	2.62	2.25	1.99	1.74	1.47	1.25	1.01

A chart showing SFR, FCR and SGR is also shown below this.

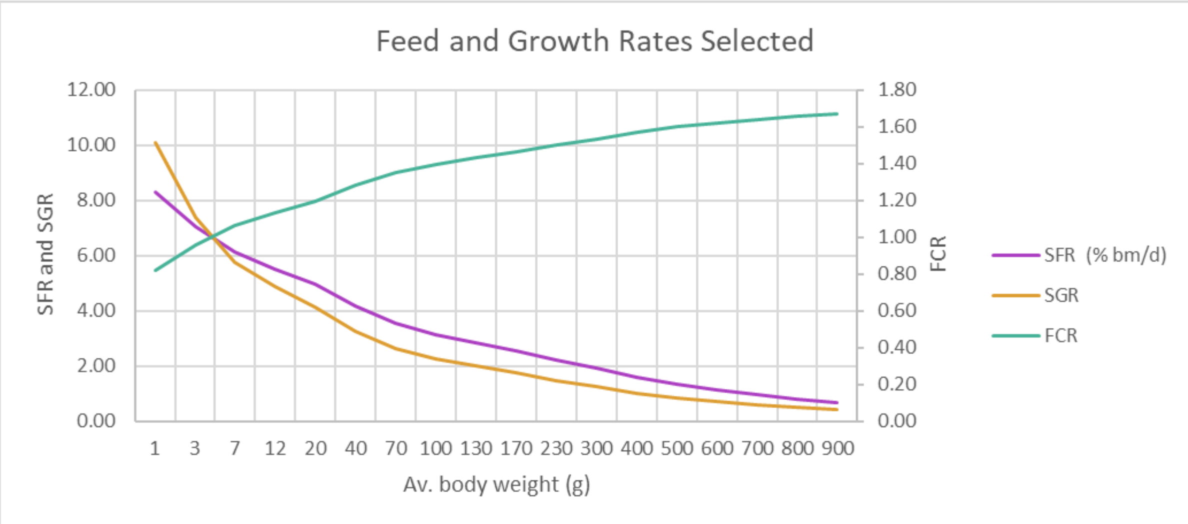


Figure 71: Chart of SFR, SGR and FCR by body weight

Once you are happy that the model is a reasonable approximation of the performance you experience on your farm, you can return to the "0-StartHere" sheet for further configuration.

Density Factor

The growth of tilapia can be affected by the density of fish in a cage. When the density is very high there can be a deterioration in water quality, especially if there is fouling on the nets. This results in a reduction in feed intake and growth. It has also been noted that growth can be lower at low densities. This may be due to the fish being more stressed, or it being more likely that feed is lost from the cage before it is eaten by the fish. Based on your experience, you can compensate for these effects in the model using the density factor table. Click on the Density Factor button on the "0-StartHere" sheet to go to the table.

Table 28: Setup table for biomass limits on growth

Biomass kg/m3	Multiplier
0	100%
5	100%
10	100%
15	100%
20	100%
25	100%
30	100%
35	97%
40	95%
45	93%
50	90%
55	87%
60	84%
65	80%
70	76%
75	72%
80	65%
85	60%
90	55%
95	50%
100	45%
105	40%
110	35%
115	30%
120	25%

You can enter different fish densities in the left column (kg/m^3), but they must be in ascending order. Enter a corresponding adjustment factor as a per cent of full growth performance in the right column. In this example, it is assumed that fish grow at their full potential until the stock density exceeds 35 kg/m^3. It then declines as stock density increases.

The density multiplier is applied to the calculated SGR in the growth models. This means that at high densities the feed amount is not reduced, but the growth achieved is lower. This results in higher FCR values (i.e. wasted feed).

Operating Costs

The Operating Costs button on the “0-StartHere” sheet takes you to a sheet where you can enter more details about your operating costs so that you can see a more informative analysis of the strategy options that you select.

The first table lists several costs that you may wish to take into account. The table provides suggested (default) values for each parameter, or you can enter your data. You can then opt to use either the default value or your value using the drop-down selector above the table.

Operating costs

For the following variables
Use Your Values or Default Values? Default Value

Return to Start

Edit labour and fuel to feed table

Labour and fuel table

	Used	Your Value	Default Value
Cost of labour per person/day	1200	800	1200
Number of Labourers	7	2	7
Cost of fuel (KES/Litre)	180	160	180
Fuel consumption (l/hr)	8	10	8
Hour of fuel use per day	4.5	3	4.5
Other varible costs (KES/kg)	10	15	10
Processing cost (KES/kg)	0	10	0
Distribution (KES/kg)	10	20	10
Annual lease cost per cage	0	1,000	0
Annual rent shore-base facilities	0	0	0
% Credit days required on fry	100%	0%	100%
% Credit days required on feed	40%	0%	40%
Interest rate on short-term credit	14.0%	15.0%	14.0%
Interest rate on long-term loans	10.0%	12.0%	10.0%
% of startup costs borrowed	50.0%	0.0%	50.0%

Figure 72: Main section for changing operating cost calculations

Some of the default values are calculated based on the growth models that you have set up. Specifically, the suggested number of labourers is calculated according to the average daily feed amount. The more feed that has to be transported to the cages and fed to the fish, the more labourers are required. You can adjust this ratio in the "LabourToFeed" table which can be reached by clicking on the "Labour and fuel table" button. Note, that only part of the table is shown below.

Feed Quantity (kg)	No. Labour	Boat hours
0	1	0.5
10	1	0.5
20	1	0.5
30	1	0.5
40	1	0.5
50	1	0.5
60	1	0.5
70	1	0.5
80	1	0.5
90	1	0.5
100	1	0.5
110	1	1
120	2	1
130	2	1
140	2	1
150	2	1
160	2	1
170	2	1
180	2	1
190	2	1
200	2	1
210	2	1

Number of labourers and boad hours in relation to daily feed amount

You can adjust the values in this table, but Feed Quantity numbers must be in increasing order from top to bottom

Multiplier for labour from average feed	3
Multiplier for boat hour from average feed	1.5

Return to Operating Costs

Return to Start

Figure 73: Setup page to link labour requirements and boat hours to feed fed per day

Firstly, you can edit the Feed quantity column, but ensure the values are in ascending order. The number of labourers required to distribute the feed quantity can then be entered in the second column. This table is also used in the calculation of fuel cost by assuming that there is a positive relationship between the amount of feed fed and the number of boat (engine) hours required. Adjust these figures to match what happens on your farm.

However, consideration should also be given to whether the number of labourers employed needs to be higher than needed for the average day. If labour is flexible and arranged on a daily or weekly basis then this may be a fair assumption. If more constant labour numbers are employed, then using an average feed rate may give an underestimate of the number of people needed. You can therefore adjust the adjacent box "Multiplier for labour from average feed". You might also consider the labour needed for harvesting when selecting this value. There is a similar multiplier for the calculation of boat hours from the average feed. This data feeds into the suggested hours of fuel use per day value in the operating costs table. For instance, if the number of labourers for a certain average daily feed amount is two, a multiplier of two would give a total of four.

If you are a farmer and know how many labourers you employ, and how many hours of boat engine you use, you can just enter those numbers in the Operating Costs table (Your Values Column). Using a ratio between feed quantity, labour and boat hours will be more useful for consultants, extension workers and students who wish to explore a wider range of production scenarios.

The next three cost categories in the Operating Cost table are expressed in terms of cost per kg of fish produced. If you have accounts from previous years and can identify your expenditure in these categories, divide that number by the number of kilograms of fish that you harvested in the same period to find the cost per kilogram. The "other variable costs" category includes any expenses that change in proportion to the quantity of fish produced. This may include expenditure on treatment chemicals, feed delivery charges, hire of equipment for harvesting etc.

As the purpose of this spreadsheet is to explore options for cage production, processing costs are not considered in any detail. However, you can include a figure in the Operating Costs table to represent these costs. Likewise, the cost of distributing fish to markets is likely to be highly variable depending on the farm, so a specific calculated figure can be included as a cost per kilogram.

The next cost categories are again very farm-specific. Firstly, if there is an annual site lease or licence fee to be paid, include that under “Annual lease cost per cage”. Divide the total cost by the number of cages that you operate (unless the fee is already on a per-cage basis).

If you have any shore-based facilities such as a feed and equipment store, staff facilities and office etc., it is assumed that these are rented, and you should enter the annual rental cost in the field “Annual rent shore-based facilities”. If they are owned, by you, it is suggested that you calculate an annual cost for these facilities and enter that as an annual rent figure. Note this rent should only relate to land-based facilities connected with production activities and not processing, as there is a separate field later on for including rental for that building.

The next three items relate to the need to access credit to purchase feed and fry. This may be in the form of an overdraft or other credit arrangement. Firstly, you are asked to enter the % credit days required for fry. If you need to borrow the full cost of the fry at the start of the rearing period and will not repay that until the end of the rearing period, enter 100%. If you do not need to access credit and can purchase fry from existing farm funds, you can enter 0%. If you only need credit to cover half of the cost, then enter 50% etc.

There is a similar line for feed. In this case, you are unlikely to purchase all the feed that is needed at the start of the rearing period, and due to the feed requirements generally increasing during the rearing period, the greater expenditure will be towards the end of the rearing period. As the interest payments depend on both the amount borrowed and the duration of the loan, even if you require credit to cover all of the feed purchases, the shorter duration of the later feed purchases will reduce the % credit days figure. As it is likely that feed will be delivered before it is paid for, some of the culture period may be free of interest charges. On the other hand, if you are not paid immediately for fish when it is sold, you cannot pay back a loan at the point of harvesting the fish. The model is not sophisticated enough to take account of all these variables. If you have access to previous data for a single batch of fish, look at the date of each feed purchase and calculate the interest payable based on the following formula:

$$I = (OD \times P \times r) / D$$

Where:

I = Interest payable

OD = Amount borrowed/overdrawn

P = Days until repayment

r = Annual interest rate

D = Days is a year (365)

Then sum the interest payable for the batch of feed purchased for the specific batch of fish. This is the total interest cost for the feed purchase. Now do the same calculation but assuming all the feed is purchased at the start of the rearing period, requiring a loan for the full amount. Use the total rearing period as the days until repayment. Now divide the actual interest cost by the amount you calculated as required if you purchased all the feed at the start and multiply that by 100 to give a percentage. Enter that value into the “% credit days required for feed” field. The default value is 40%. Alternatively, with a scenario set up to match your production, adjust this figure in the model until the charge for short-term interest payments matches your data.

The next field is the interest rate for short-term borrowing which is used in the above calculation (i.e. annual interest rate charged for overdrafts). The default value is 14% but this is very variable so should be checked and your value used where appropriate.

Note: You can only include an allowance for short-term credit to cover fry and feed, which are the two largest costs. It is assumed there will be sufficient finances available to cover other working capital requirements, such as labour and fuel.

The last two items relate to whether you take a loan to finance your start-up costs. If so, specify the interest rate (per year) that has to be paid and the percentage of the setup costs (see later) that are funded through a loan. Again, this is a considerable simplification. It enables you to see the impact of using loan financing in the early years of production. It does not account for the repayment of loan capital or the period of the loan. For the longer-term picture simply set the percentage of start-up costs to zero. The loans referred to here are long-term loans for capital equipment.

Note: that if you wish to use your values for some of the items in this list, and default values for others, you will need to copy the default values into the relevant "Your Value" field and select "Your Value" in the dropdown selector.

Once the table has been completed, the section below shows the calculated direct and fixed costs based on the overall strategy selected on the "5-Comparison" sheet. Firstly, the variable costs are shown. These are the costs that depend directly on how many fish are stocked and fed. The major costs are fry/fingerlings and feed. The annual cost of processing and distribution are also shown based on the information entered in the table above, and the cost of short-term borrowing for fry and feed. The direct variable costs are shown as % of variable production cost and as a % of total production costs.

Table 29: Output calculations for variable costs

Annual Direct (Variable) costs		*Using strategy from comparison page*	
Production	KES/Yr	% of variable production cost	% of total cost
Fry/fingerlings	20,960,148	35%	34%
Feed	29,339,885	49%	48%
Labour	3,066,000	5%	5%
Fuel	2,365,200	4%	4%
Other	2,034,464	3%	3%
Interest on feed/seed credit	1,533,521	3%	2%
Post-harvest			
Processing	0		
Distribution	2,034,464		

The next section summarises the annual fixed costs. These are the operating costs that do not depend on the number of fish stocked. Figures for maintenance and lease are included based on the values entered in the setup costs sheet and operating costs table respectively. There are then boxes for you to enter your cost information for additional items relating to post-harvest operations, such as building rent and standing power charges.

Finally in this section, you can add annual overhead costs which are simply divided between marketing and administration. You will need to enter relevant values here for your farm for the full financial analysis on the “5-Comparison” sheet to be accurate.

Table 30: Table for summarising and entering fixed costs

Annual Fixed costs	
Production	KES/Yr
Maintenance	283,611
Lease/rent on cages	0
Shore-base rent	0
Post-harvest	
Rent	0
Other fixed processing costs	0
Overheads	
Marketing	25,000
Administration	10,000
Annual interest payments	296,192

The next section simply summarises the totals as they may be presented in a typical profit and loss account.

Table 31: Profit calculations

Totals	KES/Yr
Total costs	61,652,293
Gross profit (production)	13,196,786
Gross profit (Prod. & Distrib.)	11,162,321
Net profit (production)	12,913,175
Net profit (Prod. & Distrib.)	11,162,321
Net profit (overall)	11,127,321

Finally, on this sheet, there is an analysis of the cost of tilapia production per kilogram for the chosen strategy, which is useful to compare with average sales prices. The first part shows the cost per kg for just the production operation and the second part includes both production and processing and distribution.

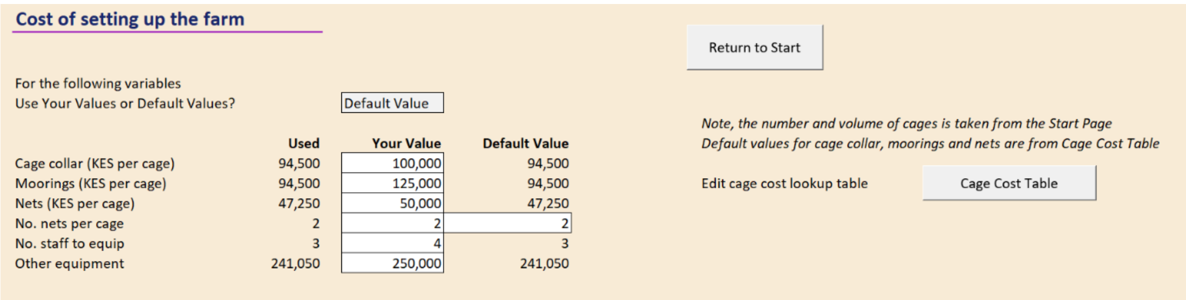
Table 32: Cost of production calculations

Cost of production	
Production only	KES/kg
Variable costs only	291
Variable & fixed costs	293
Variable, fixed and overheads	293
Production & distribution	
Variable costs only	301
Variable & fixed costs	303
Varible, fixed & overheads	303
Including equip. depreciation	308
Including equip. & other dep.	308

Farm Set-up Costs

These are the costs that are incurred before farming commences. They mainly consist of the cost of the cages and the equipment required to operate the farm including boats, harvest boxes, and safety and water quality monitoring equipment. There may also be one-off site survey and cage installation costs etc. For financial appraisal, a common approach is an investment model using a discounted cash flow of farm operations following an initial investment. However, this spreadsheet uses a more basic approach as a quick indicator of potential profitability. This is to work out the annualised cost of the equipment and other setup costs and to include it in the annual budget as depreciation.

The setup costs can be reached via the "Farm Setup Costs" button on the "0-StartHere" sheet. The first table lists data that are used in later calculations. As with the operating costs table, you can choose to use default values, or directly enter your values. If you wish to use a mix of default and own values, you must select "Your Value" and copy any default values you wish to use into the "Your Value" column. The "Used" column will confirm the values used in the equations.


Cost of setting up the farm

For the following variables
Use Your Values or Default Values? Default Value

	Used	Your Value	Default Value
Cage collar (KES per cage)	94,500	100,000	94,500
Moorings (KES per cage)	94,500	125,000	94,500
Nets (KES per cage)	47,250	50,000	47,250
No. nets per cage	2	2	2
No. staff to equip	3	4	3
Other equipment	241,050	250,000	241,050

Figure 74: Main setup section for farm establishment costs

The default values for the cage collar, moorings and nets are taken from a further lookup table which you can access via the "Cage Cost Table" button.

Table 33: Setup table for cage cost calculations

Cage vol	Collar	Mooring	Nets	Total
4.0	5000	5000	2500	12500
8.0	4050	4050	2025	10125
10.0	3400	3400	1700	8500
12.5	2600	2600	1300	6500
14.0	2250	2250	1125	5625
15.0	2500	2500	1250	6250
15.6	2250	2250	1125	5625
18.8	2000	2000	1000	5000
20.0	3500	3500	1750	8750
62.5	3750	3750	1875	9375
64.0	3000	3000	1500	7500
72.0	1500	1500	750	3750
125.0	900	900	450	2250
144.0	1100	1100	550	2750

This lists the cost of the collar, mooring and nets for a range of cage volumes (in KES per m^3 of cage volume). These values can be changed according to local price information. As with other lookup tables, the cage volume data must be ordered from the lowest at the top to the highest at the bottom.

The cost information for these cage elements shown on the farm setup costs page is taken from this table by looking up the volume of the cages from the “0-StartHere” page, reading the corresponding cost per m^3 from the table and multiplying that by the cage volume before returning that value to the farm setup cost table. As with other lookup tables, when the specified cage volume is between two values in the table, data from the row with the lower value will be used.

The table also allows you to enter the number of nets that would be purchased per cage (as it is common to have spare nets and nets of different mesh sizes) and the number of staff for whom safety equipment such as life jackets need to be purchased. The default value shown here will be the same as the default value shown for the operating costs (they are based on the same calculations). If you use your value in the operating cost table, you should also use your value in the setup cost table.

The “Other equipment” category should include all other equipment needed for the cages including feeders (if used) and water quality monitoring equipment.

The setup cost calculations continue with a second table:

Table 34: Additional farm cost data setup

Setup costs

Item	Category	Number	Item Cost	Total Cost	Life (years)	Annualised cost	Annual maintenance %	Maintenance
Cage collar	Equipment	8	94,500	756,000	10	75,600	2.5%	18,900
Moorings	Equipment	8	94,500	756,000	10	75,600	5.0%	37,800
Nets	Equipment	16	47,250	756,000	3	252,000	10.0%	75,600
Boat	Equipment	1	35,000	35,000	10	3,500	2.5%	875
Outboard engine	Equipment	1	70,000	70,000	7	10,000	10.0%	7,000
Diving equipment	Equipment	0	75,000	0	5	0	5.0%	0
Safety and clothing	Equipment	3	12,500	37,500	2	18,750	0.0%	0
Other equipment	Equipment	1	241,050	241,050	5	48,210	0.0%	0
Extension services/training	Other	1	12,500	12,500	5	2,500	0.0%	0
Survey/Reg/Licences	Other	1	500,000	500,000	5	100,000	0.0%	0

This lists further equipment and setup costs which you should adjust to suit actual values. To the right of these values are calculations for depreciation. The expected life of each item is specified in years. This allows an annualised cost of start-up to be included in profitability calculations (i.e. depreciation). If you wish to assess financial viability over a shorter time frame than the actual life of the equipment, you can enter that shorter period in the “Life” column. However, note that in some cases, equipment may then have second-hand value (e.g. boat) which would not then be taken into account. You can also specify a percentage of the set-up costs as an annual maintenance cost, which is then included in the operating costs sheet.

The final content on this page is a set of totals that are used on the “5-Comparison” sheet to provide a further indicator of financial viability. This table simply sums data from elsewhere on the sheet:

Table 35: Calculation of total setup cost

Totals	
Total setup cost	3,517,500
Total equipment cost	3,005,000
Other set-up costs	512,500
Annulised setup cost	637,667
Annualised setup cost ex. Other	535,167

Mortality rates

The modelling of mortality rates is perhaps the most problematic element of the biological model, as they are either unpredictable or tend to increase under certain environmental conditions which may be site-specific or seasonal. Furthermore, in this spreadsheet model, mortalities include losses from any cause, including predation, escapes, or theft. In practice, mortality rates and other losses can be difficult to monitor, especially for reasons other than disease. The model assumes relatively low mortality rates and that these mainly occur after first stocking, or the handling of fish when taking an interim harvest, or near the end of the production cycle when stock densities are at their highest.

Each of the scenario sheets includes a chart showing assumed cumulative mortalities expressed as a percentage of stock (line), and also as biomass lost (vertical bars).

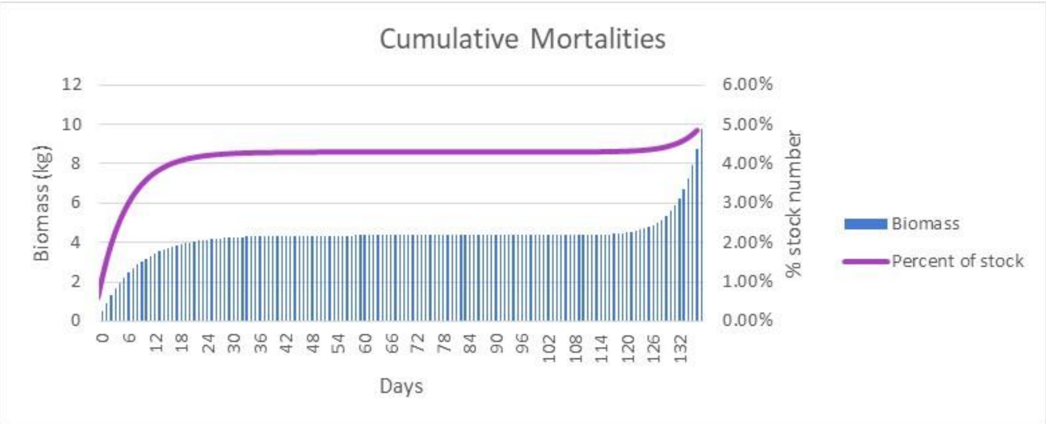


Figure 75: Chart of cumulative mortalities showing peaks at start and end of cycle

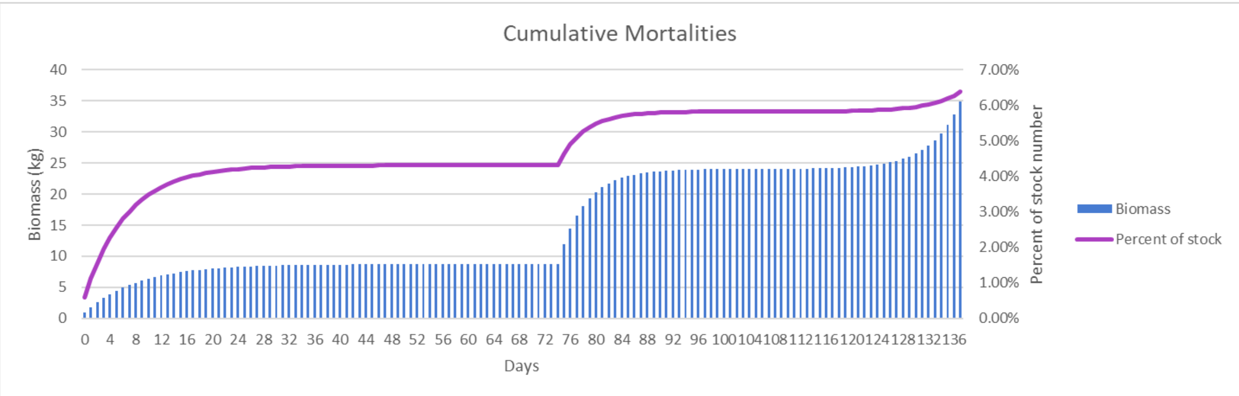


Figure 76: Chart of mortalities with interim harvest

The mortality formula is simply an exponential function with the input values being the number of mortalities on a specified day (e.g. day of stocking, day of partial harvest or day of final harvest) and a parameter that determines the daily rate of decay from that number. The number of mortalities on the first day is calculated based on your estimate of the percentage of stocked fish that die within the first 24 hours after stocking.

Mortalities on Day (t) = Mortalities on first day x EXP(L_i*t)

Where L_i is the rate at which the daily number of mortalities declines, and t is the number of days after stocking.

As the spreadsheet calculates the stock numbers daily, this can be simplified to:

Mortalities on Day (t) = Mortalities on the previous day x EXP(Li)

The L value is always negative so mortalities decline after the initial losses. Values of between -0.05 and -0.25 are suggested.

The effect of changing the L value can be seen in the charts below. Both assume a first-day mortality of 0.6% of the stocked fish, but the first has an L value of -0.05 and the second -0.5.

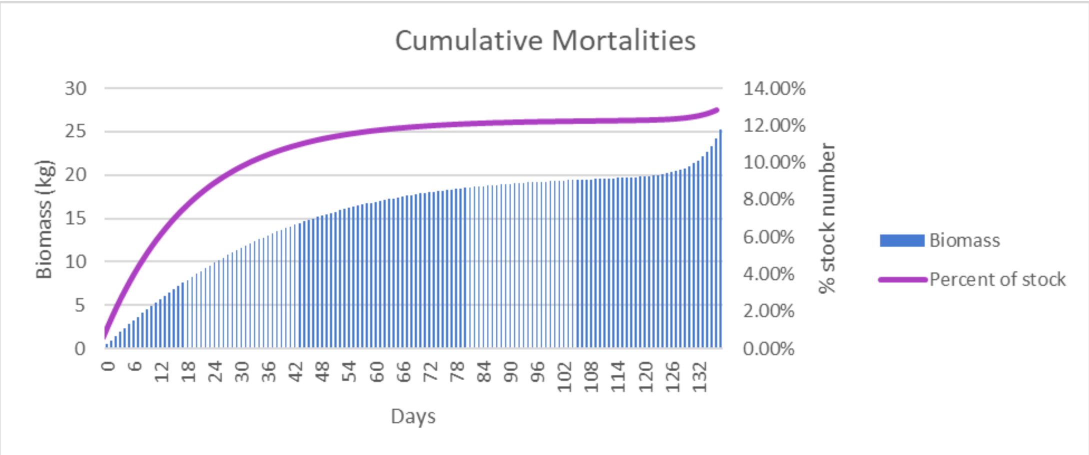


Figure 77: Cumulative mortalities with L value of -0.05

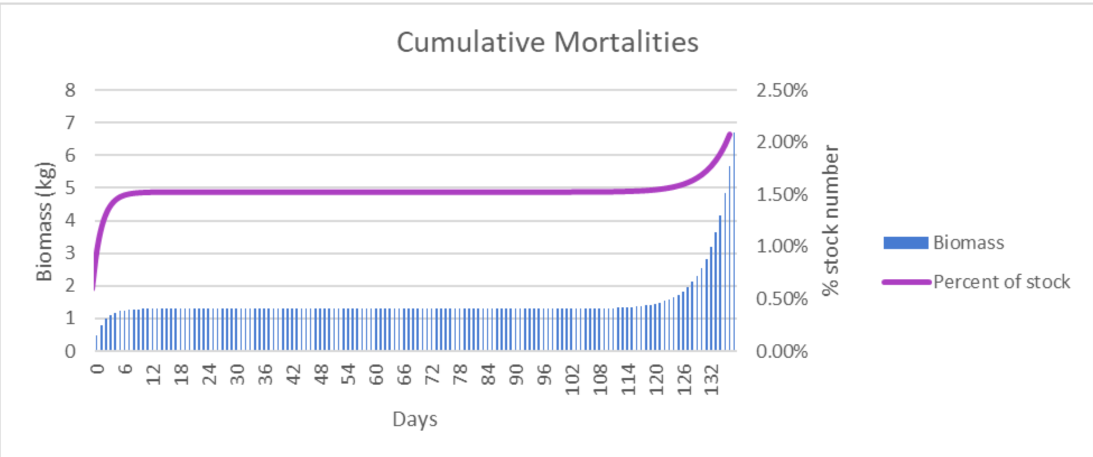


Figure 78: Cumulative mortalities with L value of -0.5

It can be seen that more negative values steepen the mortality curve, so the daily rate reduces at a greater rate resulting in far fewer mortalities overall. The suggested initial values for first-day mortalities and Li are 0.6% and -0.15 respectively.

The same equation (although with different parameter values) is used to model mortalities after partial harvest of a cage, where the remaining fish have been stressed.

To model an increase in mortalities in the late stage of the production cycle a slightly modified equation can be used:

$$\text{Mortalities on Day (t)} = \text{Mortalities on final day} \times \text{EXP}(L_f*(T-t))$$

This effectively reverses the curve so that mortalities increase to a fixed final value. Again, the slope of that curve is determined by the L value which remains negative. Taking an example where 0.1% of the stock dies on the final culture day, the following charts illustrate the impact of L values of -0.05 and -0.5

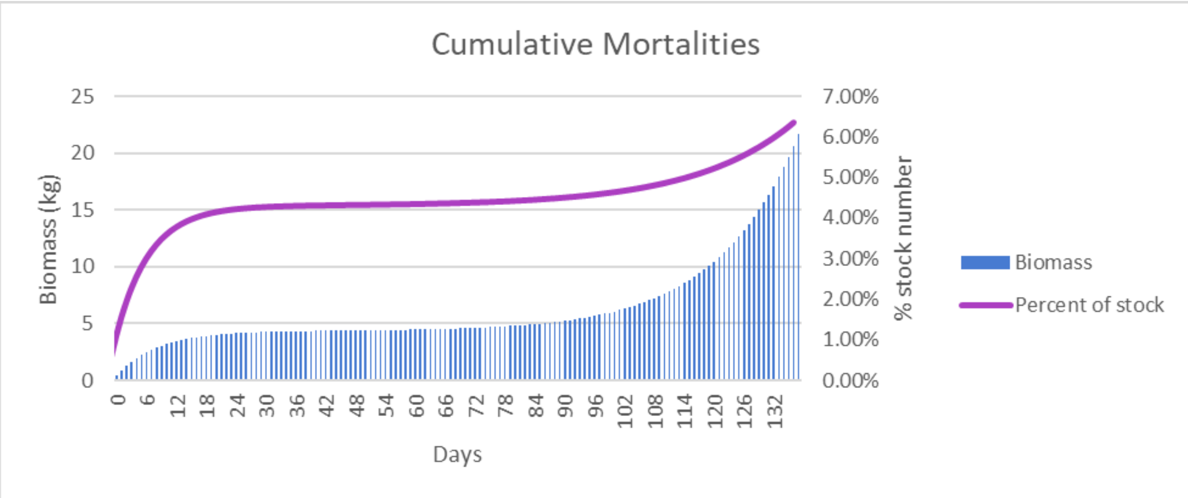


Figure 79: Final mortality pattern with 0.1% loss of stock on final day and L value of -0.05

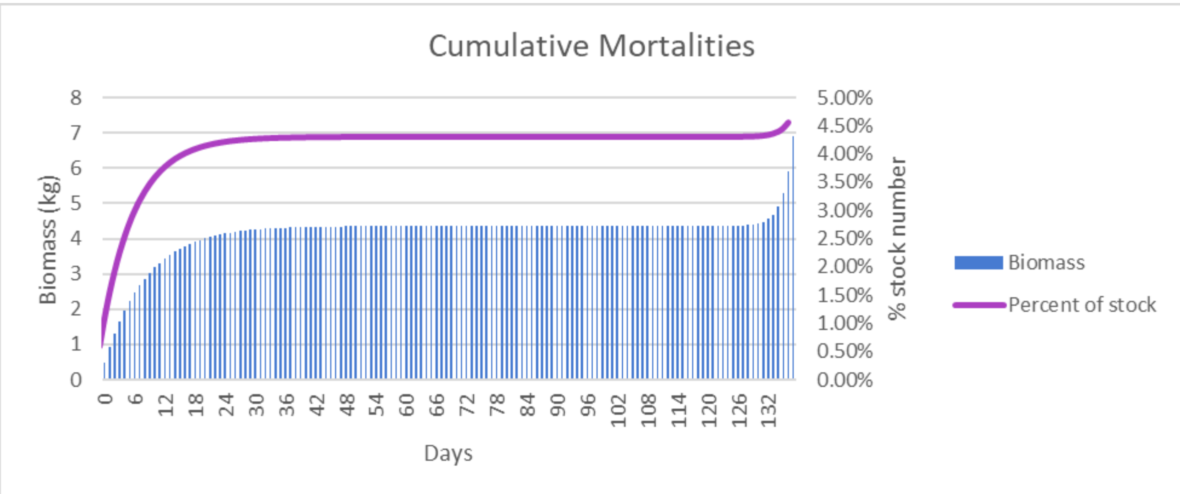


Figure 80: Final mortality pattern with 0.1% loss of stock on final day and L value of -0.5

In this example, the less negative number means a shallow slope, so overall there are substantially higher mortalities than in the second example where the increase in mortalities happens faster but much later. The suggested initial values for final-day mortalities and L_f is 0.1% and -0.2 respectively.

It can also be seen from these charts, that mortalities at the end of the cycle have a much greater impact in terms of biomass and hence result in much greater financial loss.

Fine-tuning the mortality models is therefore very important for improving the accuracy of the financial projections.

Size variability

Within any population of fish, there will be a natural size variation between individuals. This will depend partly on genetic diversity, but also on management practices (such as grading and control of feeding). For modelling, it is assumed that sizes are normally distributed around the mean value (i.e. more fish closer to the mean weight and fewer that are significantly larger or smaller, but an equal number of smaller and larger fish). If this is not the case, then the model may give misleading results. In particular, note that the size distribution is calculated in 100g bands, so if the fish are grown to say 200g or less, there will be insufficient resolution in the charts to show a normal distribution.

The spread of sizes can be controlled by adjusting the "Coefficient of variation" (cv) in the advanced setup section.

Size variability		
Coefficient of variation	24%	*<<Suggested value 22 to 26*

Figure 81: Data entry for Coefficient of Variation

CV is calculated as standard deviation divided by the mean and is usually expressed as a percentage.

$$CV = \frac{Standard\ deviation}{mean}$$

You can find this number for your typical harvests by individually weighing a large sample of fish and recording the weights in a column in Excel. You can then use the built-in Excel formulas to find the mean of the numbers and the standard deviation.

Normal values for CV are generally between 22 and 26%. The higher the value the greater will be the spread of sizes around the mean.

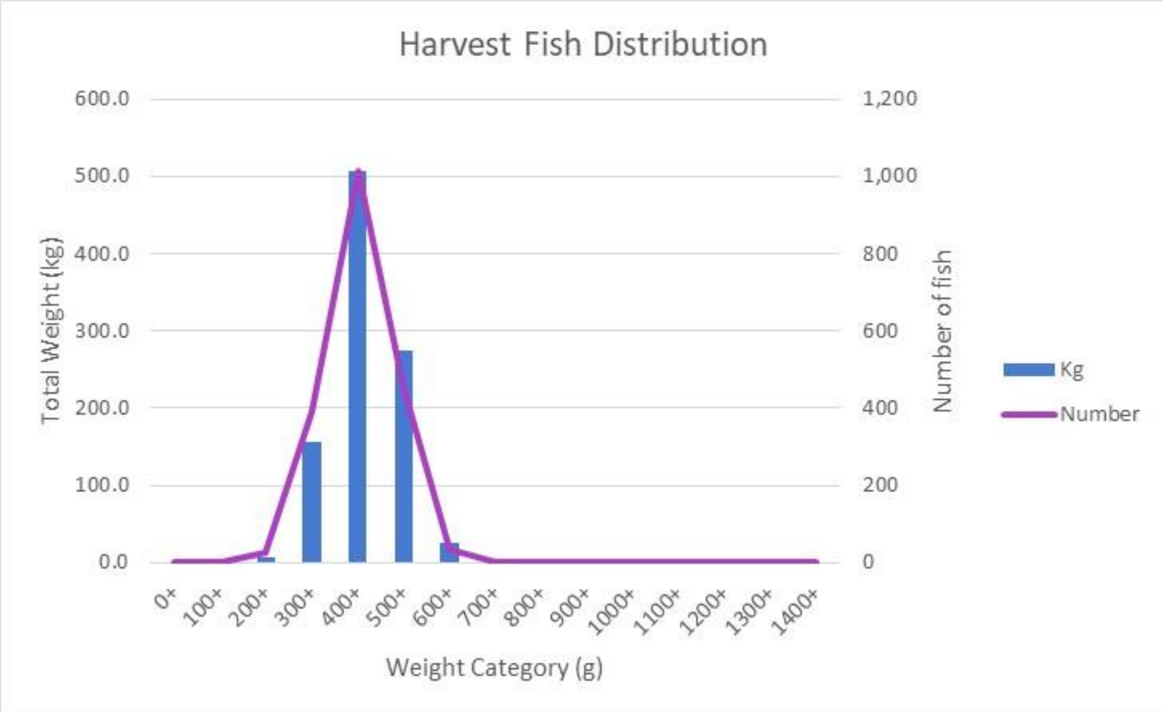


Figure 82: Example distribution with CV set to 15%

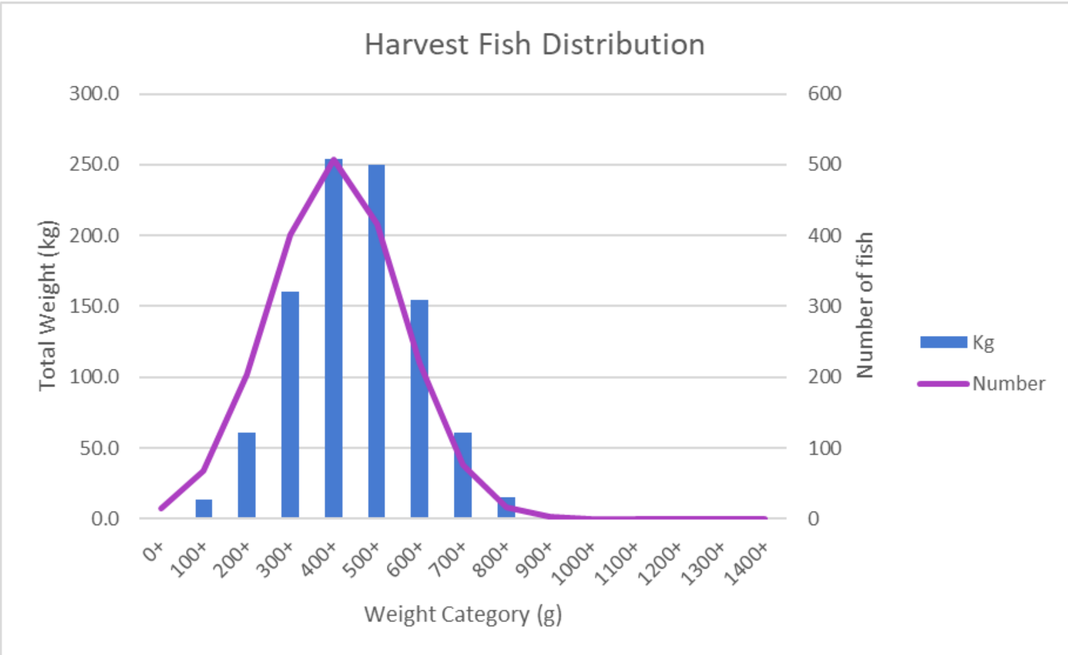


Figure 83: Example distribution with CV set to 30%

Profit/loss calculations

If you take the time to ensure the setup and operating cost assumptions are realistic, then the spreadsheet will give some further indication of financial viability through the last section of the "5-Comparion" sheet. The spreadsheet does not attempt to generate a realistic set of accounts (e.g. balance sheet and trading and profit/loss). Rather it produces some financial indicators, using management accounting methods and greatly simplified assumptions.

The layout is that of a trading, profit and loss account, but it brings in consideration of the investment costs through the inclusion of depreciation, and interest payments on loans. Short-term loans such as overdrafts to fund feed and fry are optionally included in the variable operating costs section by selecting "yes" under "Include the cost of short-term credit for fry and feed?" at the top of the worksheet. Interest payments on long-term loans (not including any repayment of the capital) are a kind of fixed operating cost. However, to assess the underlying viability of a business it is often preferable to exclude the cost of financing (hence the option of including or excluding interest on short-term loans). In this financial summary, the long-term interest payments are excluded from the fixed cost section but included immediately below for the calculation of annual return, which also includes depreciation on fixed assets. Note that income tax is excluded as that is calculated on the final profit of a business.

Table 36: Profit and loss calculations

Profit/Loss calculation		
	KES	
Annual income from sales	**72,496,003**	
Less variable costs:		
Cost of feed	28,760,492	
Cost of fry/fingerlings	20,006,020	
Labour	3,066,000	
Fuel and other inputs	4,399,664	
Processing & distribution	2,034,464	
Interest on feed & seed credit	1,533,521	
Gross profit	**12,695,842**	17.5%
Less fixed costs:		
Lease, processing & maintenance	283,611	
Administration and sales	35,000	
Net profit	**12,377,231**	17.1%
Less		
Depreciation	1,098,476	
Long term loan interest payments	296,192	
Annual return	**10,982,563**	15.1%

Adjacent to the data table is a waterfall chart which displays these figures to show the income to the enterprise as the leftmost bar and then how that income is spent leading to the final bar at the right which represents "profit" or if negative, "loss" before tax.

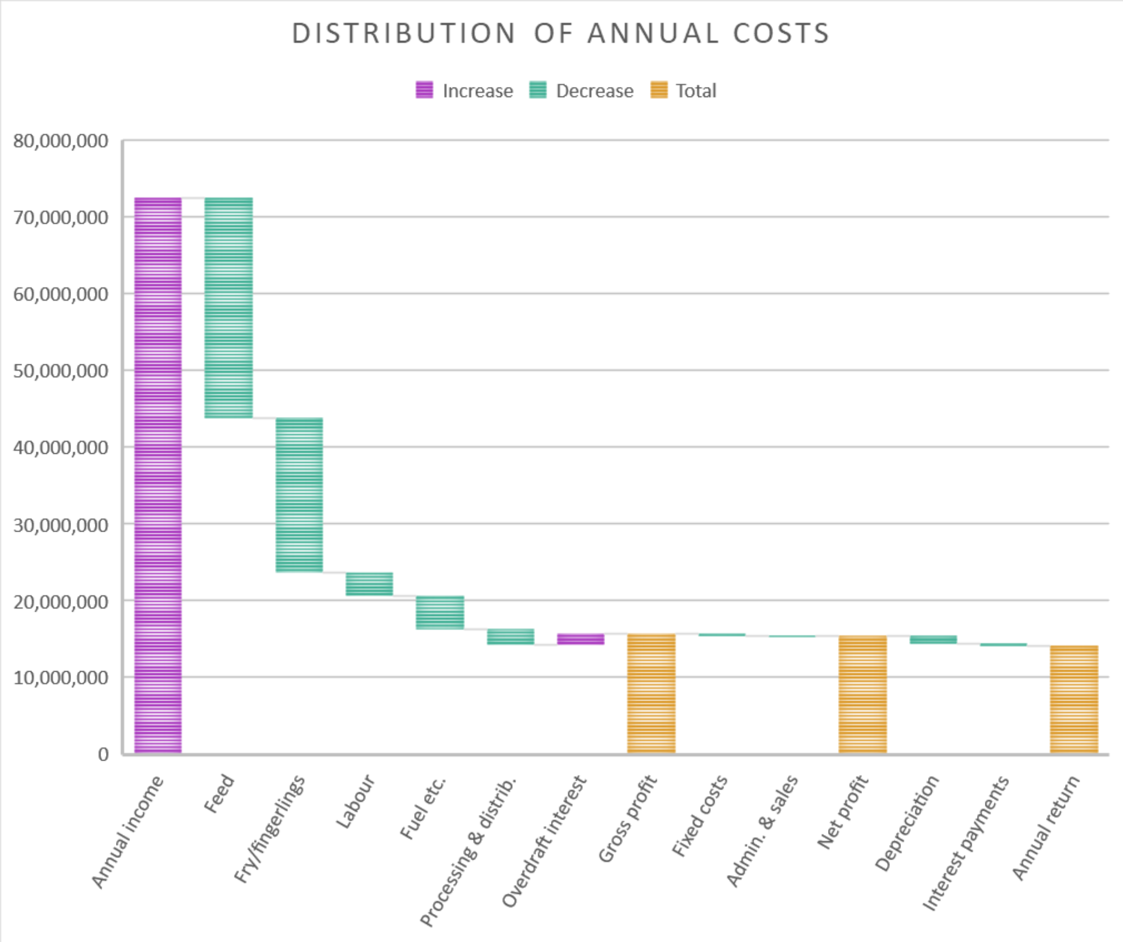


Figure 84: Waterfall chart to show how costs are distributed

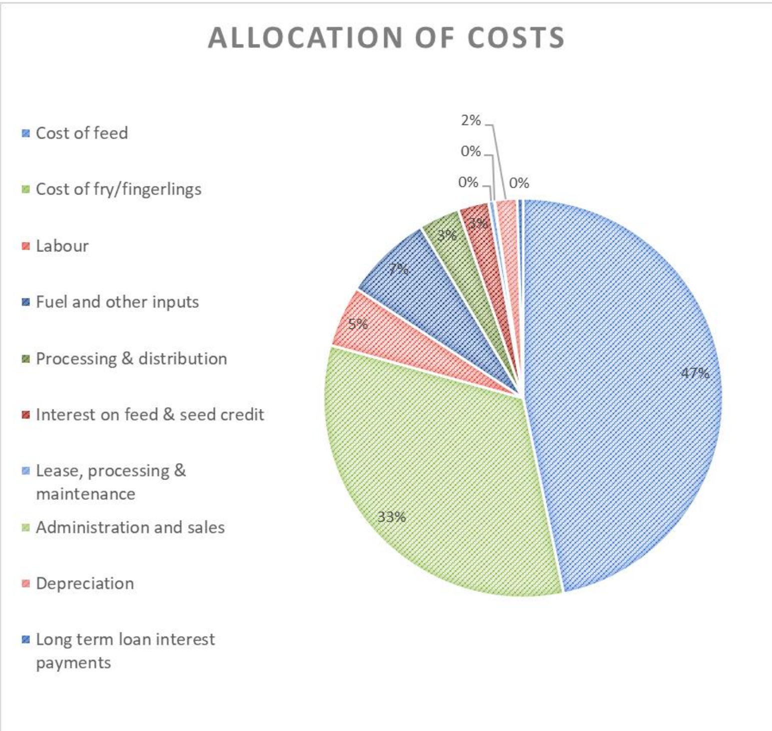


Figure 85: Pie chart of costs

A final chart displays the costs as a pie chart. This is to help focus on those which are more significant and might be addressed through strategic or managerial steps such as improving the feed conversion efficiency to better control feed costs.

Other financial indicators

A final section on this sheet calculates several other financial indicators that can be useful for comparison between scenarios. These are taken from Ngugi et. al (2007).

The breakeven price is the average selling price needed to cover either just the variable production costs or the total costs, e.g.

Variable cost breakeven price = Total Variable Costs / total fish produced

Total cost breakeven price = Total costs / total fish produced

Table 37: Other financial indicators

Other indicators		
Variable cost breakeven price per kg fish	293.94	KES
Total cost breakeven price per kg fish	302.36	KES
Breakeven yield (above total costs)	172,626	Kg/yr
Breakeven yield (above variable costs)	167,818	Kg/yr
Gross profit/loss per m^3	8,863	KES/yr
Net operating profit/loss per m^3	8,641	KES/yr
Overall profit/loss per m^3	7,667	KES/yr

The breakeven yield is the quantity of fish that needs to be produced at the actual average selling price before a margin can start to be made. E.g.

Breakeven yield above total costs = Total costs / Average selling price per kg

Breakeven yield above variable costs = Variable costs / Average selling price per kg

Finally, the margins per m^3 of cage volume are calculated.

Gross profit/loss per m^3 = Gross profit / volume of cages

Net operating profit/loss per m^3 = Net profit / volume of cages

Overall profit/loss per m^3 = Overall profit / volume of cages

Note that the data and calculations shown here are not intended to reflect typical or even actual performance. Best estimates were used as placeholders for actual data during the development of this spreadsheet. Users should update the cost data to match their situation before using any results from this section to evaluate specific scenarios.

Consolidation of different models

In some circumstances you may wish to compare strategies based on different biological assumptions. For instance growth at different temperatures, the use of different feeds or different assumptions concerning FCR or mortality rates etc. In order to do this, an additional sheet “Consolidate” has been added to the end of the workbook. This is essentially the same format at the “5-Comparison” sheet. However, instead of taking input data directly from the four strategy sheets, you can copy and paste data here from the “5-Comparison” sheet. There is a range selector and action button to do this to the right of the first strategy comparison chart.

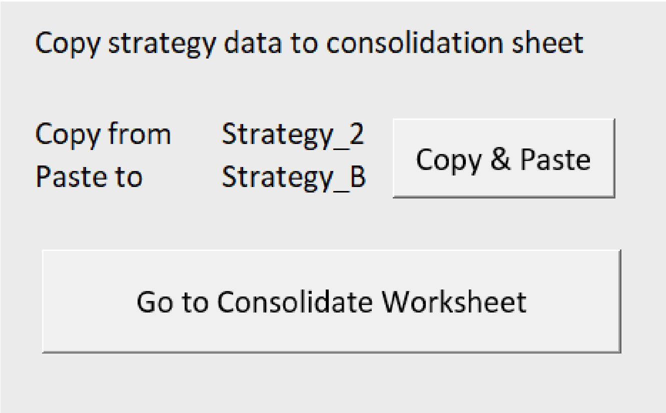


Figure 86: The strategy cut & paste selector

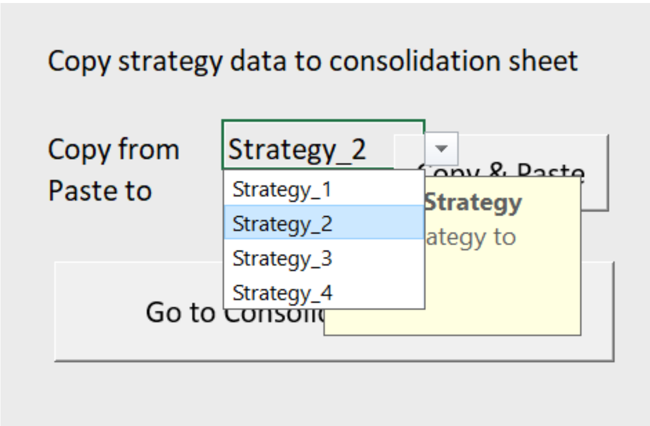


Figure 87: Selecting the source strategy to copy to the Consolidation sheet

First select the strategy on the “5-Comparison” sheet that you wish to copy and paste to the “Consolidate” sheet. These are labelled “Strategy_1” to “Strategy_4”. Then select which position you wish to paste the range into on the “Consolidate” sheet, these are labelled “Strategy_A” to “Strategy_D”. Once the correct source and destinations have been chosen, click on the “Copy & Paste” button. You can then change your biological variables and then select another cage strategy to copy to the consolidate sheet, using a different destination range. Once the desired strategies have been copied to the Consolidate sheet, click on the “Go to Consolidate Worksheet” button. The results can be compared on that sheet in the same way as for the 5-Comparison sheet by allocating cages to the selected strategies.

Compare scenarios with different base assumptions

Annual comparison for 1 cage

Return to 5-Comparison

	Strategy A Standard	Strategy B Double	Strategy C Short	Strategy D Partial
Individual cage volume (m^3)	27	27	27	27
Annual production (kg)	2,390	4,513	3,883	3,412
Annual income (KES)	869,095	1,631,737	1,188,015	1,178,698
Annual feed use (kg)	3,313	6,563	4,646	4,562
Fingerlings used (No.)	5,028	10,056	17,189	10,056
Feed cost (KES)	338,812	671,152	470,723	458,600
Fry/Fingerling cost (KES)	211,691	423,382	687,558	402,245
Income less feed and fry (KES)	318,592	537,203	29,734	317,853

The table above summarises the results for each of the 4 selected strategies.
You can now allocate your cages to the stragegies for a total annual production estimate

Figure 88: The pasted strategies A-D on the "Consolidate" sheet

Annual total for all cages

Number of cages to allocate (from start sheet) 8

	Strategy A Standard	Strategy B Double	Strategy C Short	Strategy D Partial		
Number of cages per strategy	1	4	0	3	8	OK
Individual cage volume (m^3)	27	27	27	27		**TOTAL**
Total cage volume (m^3)	27	108	0	81		216
Percentage of total cage volume	13%	50%	0%	38%		100%
Annual production (kg)	2,390	18,052	0	10,237		30,679
Percentage of total production	8%	59%	0%	33%		100%
Annual income (KES)	869,095	6,526,950	0	3,536,095		10,932,140
Percentage of annual income	8%	60%	0%	32%		100%
Annual feed use (kg)	3,313	26,253	0	13,687		43,253
Fingerlings used (No.)	5,028	40,224	0	30,168		75,421
Feed cost (KES)	338,812	2,684,609	0	1,375,801		4,399,222
Fry/Fingerling cost (KES)	211,691	1,693,528	0	1,206,735		3,111,954
Income less feed and fry (KES)	318,592	2,148,813	0	953,559		3,420,964
Percentage of income less feed and fry	9%	63%	0%	28%		100%

NB. Ensure data on the SetupCosts and OperatingCosts sheets match the selected strategies for the following analysis to be meaningful

Figure 89: Allocation of cages to strategies A-D for total annual results

Since these scenarios include the cost of fry and feed and the price obtained for the sold fish, you can also adjust these values in addition to the biological variables between different strategies. However, the remaining financial analysis on the page will depend on the current values, so you should not change the size of your farm (number or sizes of cages for instance), when you are changing other variables for each strategy.

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