

## Malawian Aquaculture Pond Ecosystem Challenge - Instructor Information

**Topic:** This case study challenges students to design a pond that will provide supplemental food security to a rural Malawian village. Working in pairs, the students design an aquaculture pond with a food chain that will support either shrimp or fish as a food source. In the process they apply concepts of primary and secondary production, trophic efficiency, trophic levels and sustainability. At the end of the exercise, students present their ponds to the class and the most successful pond is commended.

**Learning Objectives:** Students will be able to...

- Describe how biomass flows in ecosystems.
- Understand how detritus is generated in ecosystems.
- Explain why secondary production is less than primary production.
- Calculate secondary production using trophic efficiencies.

**Origin:** This case study was developed to accompany SimBio's SimUText Ecosystem Ecology chapter. It assumes that students are familiar with trophic efficiency, primary and secondary production, decomposition and nutrient ratios.

**Author:** Jessica Coyle, Saint Mary's College of California, [jrc16@stmarys-ca.edu](mailto:jrc16@stmarys-ca.edu)

**Keywords:** trophic efficiency, production, detritus, aquatic ecosystem, food

**Usage:** This case study is a stand-alone activity that could be implemented during a lecture-format class or as a take-home activity. The activity is designed as a handout which is provided at the end of this document. If the activity is completed during class, the instructor can use the slides provided to give background information rather than have students read the background information on the handout. These slides also contain a pre- and post-activity assessment.

This case study was originally developed in an upper-division introductory ecology course with 16 students. It was utilized during a 90 minute lecture on production and nutrient cycles to reinforce concepts that students already learned by completing the SimBio SimUText chapter on Ecosystem Ecology. However, the activity is meant to be adapted for any setting in which students have the relevant background knowledge. Students should be familiar with terminology used in ecosystem ecology (e.g., pool, flux, production, turnover, residence time). The instructor can steer weaker students toward the less complex food chain (shrimp) and stronger students toward the more challenging food chain (chambo).

### Materials Included

- *Malawian Aquaculture Pond Ecosystem Challenge.pdf* This document containing instructions for teaching the activity and student worksheets.
- *Malawian Aquaculture Pond Ecosystem Challenge Editable Student Worksheets.docx* A word document of the student worksheets found in the previous pdf file in case the instructor needs to modify them.
- *Malawian Aquaculture Pond Ecosystem Challenge Slides.pptx* A powerpoint file with slides that introduces the activity with background on Malawi and aquaculture.

- *Figures.zip* A folder containing svg vector images of the original art created for this activity along with png versions of them.
- *Teaching Notes.pdf* A document describing how this activity was used in the classroom.

### **Potential schedule of usage in class along with discussion topics**

- 1. Background (10 - 20 min)** Present background information and the challenge. Orient students to the data tables. Give verbal instructions that mirror the written instructions. The activity works best if the instructor shows the students how to fill out the diagrams using the shrimp diagram and then allow them to choose Catfish or Chambo or add inputs to Shrimp.
- 2. Worktime (30 - 40 min)** Students work alone or in pairs to construct a pond and calculate its maximum secondary production.
  - a. Distribute Instructions (can be double sided), data tables and diagrams. Data tables and diagrams should be single sided so students are not flipping back and forth. These materials can be found starting on page 5 of this document.
  - b. Suggest that all students start with a food chain that has no inputs (fertilizer or fish meal) to see what the baseline production is. Then add one input to see how this changes production. From this decide whether adding that input might be cost-effective.
- 3. Discussion (10 min)** This wrap-up discussion should at least cover the take-away messages in part a.
  - a. Whose pond was most productive?
    - i. Shrimp are highly productive on low inputs because they are invertebrates that feed at a low trophic level.
    - ii. Feeding fish meal is more energetically efficient than adding fertilizer to increase primary production because less energy is lost. However, in the real world the relative cost of fertilizer and fish meal will determine which is more cost effective.
    - iii. Why don't the fluxes add to 1? Respiration is missing from the diagrams. Where would you add this in?
    - iv. We are using GPP as the basis of the food chain because that is how production is usually estimated in aquatic ecosystems. What are consumers actually using? How will this affect estimates?
    - v. Recycling non-consumable parts of the harvested species into the detrital pool could increase production for species that eat detritus.
  - b. Other considerations that do not enter these calculations
    - i. How much of the secondary production is harvestable each year?
      1. Production = growth of adults + addition of new juvenile
      2. Life history has important role in harvestable biomass produced.
    - ii. How do aquatic species get their oxygen?

1. If ecosystem respiration > photosynthesis the pond will become anoxic and the ponds would need bubblers to sustain DO.
  2. Inputs can raise respiration to be greater than photosynthesis, especially through detrital pathway (bacteria).
- iii. High levels of fertilizer can be toxic.
  - iv. What economic and cultural considerations are not a part of these calculations?

### **Modifications**

- Demonstrate a basic ecosystem without inputs and then challenge the students to calculate the effect of adding particular inputs (e.g. production with input / production without input). Assign different inputs or levels of input to different groups.
- Assign activity as homework and just have a discussion of the results during class.

### **Additional References**

Diana, J. S., C. K. Lin and P. J. Schneeberger. 1991. Relationships among nutrient inputs, water nutrient concentrations, primary production, and yield of *Oreochromis niloticus* in ponds. *Aquaculture* 92: 323-341. DOI: 10.1016/0044-8486(91)90038-9

## Answer Key

### Rates of production

Scenario:	Base production	Fish meal (per 1 kg m <sup>-2</sup> y <sup>-1</sup> )	Inorganic fertilizer (0.5 - 1.0 kg m <sup>-2</sup> y <sup>-1</sup> )	Chicken manure (2 kg m <sup>-2</sup> y <sup>-1</sup> )
NPP	1 kg m <sup>-2</sup> y <sup>-1</sup>	1 kg m <sup>-2</sup> y <sup>-1</sup>	9.5 kg m <sup>-2</sup> y <sup>-1</sup>	8.8 kg m <sup>-2</sup> y <sup>-1</sup>
Shrimp	0.204 kg m <sup>-2</sup> y <sup>-1</sup>	N/A	1.939 kg m <sup>-2</sup> y <sup>-1</sup>	2.012 kg m <sup>-2</sup> y <sup>-1</sup>
Catfish	0.024 kg m <sup>-2</sup> y <sup>-1</sup>	+ 0.067 kg m <sup>-2</sup> y <sup>-1</sup>	0.227 kg m <sup>-2</sup> y <sup>-1</sup>	0.292 kg m <sup>-2</sup> y <sup>-1</sup>
Chambo	0.018 kg m <sup>-2</sup> y <sup>-1</sup>	+ 0.090 kg m <sup>-2</sup> y <sup>-1</sup>	0.173 kg m <sup>-2</sup> y <sup>-1</sup>	0.160 kg m <sup>-2</sup> y <sup>-1</sup>

### Total annual consumable production

production rate x human consumption efficiency (shrimp = 0.8, fish = 0.9) x 500 m<sup>2</sup> pond

Scenario:	Base production	Fish meal	Inorganic fertilizer	Chicken manure
Shrimp	81.6 kg yr <sup>-1</sup>	N/A	775.6 kg yr <sup>-1</sup>	804.8 kg yr <sup>-1</sup>
Catfish	10.8 kg yr <sup>-1</sup>	+ 30.1 kg yr <sup>-1</sup>	102.1 kg yr <sup>-1</sup>	131.4 kg yr <sup>-1</sup>
Chambo	8.1 kg yr <sup>-1</sup>	+ 40.5 kg yr <sup>-1</sup>	77.8 kg yr <sup>-1</sup>	72 kg yr <sup>-1</sup>

### Total annual nutrition provided

Fish: 950 kcal and 160g protein per kg, Shrimp: 1060 kcal and 200g protein per kg

Scenario:	Base production	Fish meal	Inorganic fertilizer	Chicken manure
Shrimp	86,496 kcal 16,320 g protein	N/A	822,136 kcal 155,120 g protein	853,088 kcal 160,960 g protein
Catfish	10,260 kcal 1,728 g protein	+ 28,595 kcal + 4,816 g protein	96,995 kcal 16,336 g protein	124,830 kcal 21,024 g protein
Chambo	7,695 kcal 1,296 g protein	+ 38,475 kcal + 6,480 g protein	73,910 kcal 12,448 g protein	68,400 kcal 11,520 g protein

# Malawian Aquaculture Pond Challenge

## Background

- Malawi is an east African country of primarily rural subsistence farmers, most of whom get the majority of their protein from fish harvested from Lake Malawi.
- Fish populations are in decline and many people are turning to subsistence aquaculture to support protein needs.
- Aquaculture is the cultivation of species that live in freshwater or marine systems. In Malawian aquaculture, a farmer will typically build a pond on their land in which they grow fish. Common species include Chambo (a local favorite from the lake) and Catfish.

## The Challenge

Your village can no longer support its dietary needs on the fish that fishermen are able to harvest from the lake. You must design a pond that maximizes the sustainable harvest of a protein-supplying species, while minimizing the cost of the inputs needed to support this secondary production.

## Constraints

Your village has set aside a 500 m<sup>2</sup> area for you to build a pond. You can choose to cultivate one of three species as a protein source: chambo, catfish or shrimp. Chambo and catfish both provide 95 kcal and 16g protein per 100g consumed, whereas shrimp provide 106 kcal and 20g protein per 100g consumed. Humans cannot consume all of the biomass that fish or shrimp provide because the skeletons cannot be eaten. Hence, human consumption efficiency of fish is 80% and of shrimp is 90%. Unconsumed biomass could be recycled by returning the fish and shrimp carcasses to the pond as detritus.

You will need to support your consumable species with a food source: algae (primary producers), zooplankton (primary consumers of algae), or fish meal. Table 1 shows what each of these species are able to eat and their trophic efficiencies when consuming those food sources (broken down into consumption, assimilation and production efficiencies). The table also contains trophic efficiency data for other species that may occur in your pond's food chain. Both catfish and shrimp will consume detritus (dead organic matter) if it is available. The decomposers in your pond will recycle any detritus that accumulates and is not consumed by other species. You can supplement the detritus in your pond by adding the manure generated by your village's chickens.

Initial experiments show that gross primary production (GPP) by algae in your pond will be 1 kg m<sup>-2</sup> yr<sup>-1</sup>. However, you can increase this rate by adding fertilizer. Figure 1 shows how primary production of algae in your pond will change with added inorganic or organic fertilizer (in the form of chicken manure).

## Record your pond set up here:

Cultivated species: \_\_\_\_\_

Chicken manure supply rate: \_\_\_\_\_

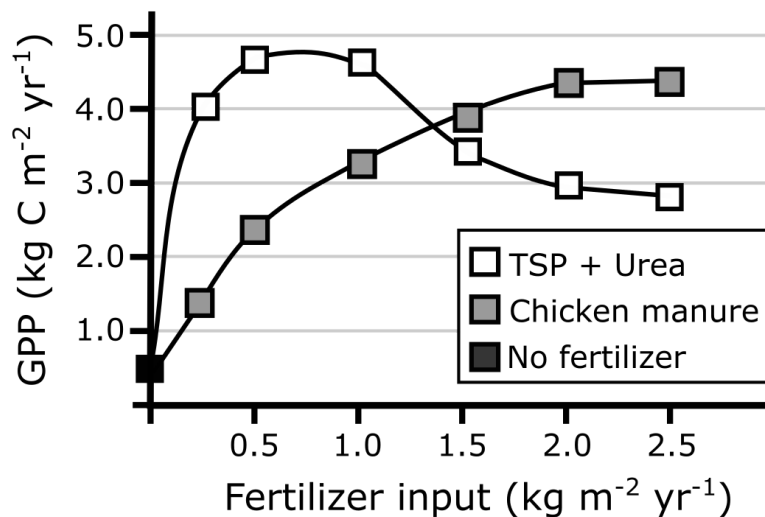
Inorganic fertilizer supply rate: \_\_\_\_\_

Fish meal supply rate: \_\_\_\_\_

**Disclaimer:** The trophic efficiencies and data in this exercise are hypothetical and, although they are biologically reasonable, are not based on an empirical data source.

**Table 1. Trophic efficiency of organisms in the aquaculture pond ecosystem.**

	Species	Eats	Consumption efficiency	Assimilation efficiency	Production efficiency
<b>Consumable species</b>	Chambo	fish meal	1	0.9	0.1
		zooplankton	0.9	0.9	0.1
		algae	0.1	0.9	0.02
	Catfish	fish meal	1	0.9	0.07
		algae	0.9	0.9	0.02
		detritus	0.9	0.9	0.05
	Shrimp	algae	0.9	0.6	0.25
		detritus	0.9	0.6	0.3
<b>Supporting species</b>	Zooplankton	algae	0.9	0.9	0.25



**Figure 1. Primary production in fish ponds fertilized with inorganic (TSP + Urea) or organic (chicken manure) fertilizers at different concentrations.** Inorganic fertilizer contains only nitrogen (from urea) and phosphorus (from TSP, triple superphosphate). GPP was measured using the light-dark bottle technique and the units are in kg carbon fixed by photosynthesis. For ease of calculations, assume that GPP is equal to NPP and that algae are 50% carbon by mass. Hence, 1 kg C fixed = 2 kg algae produced.

## Step-by-step Instructions for Completing the Pond Ecosystem Diagram

1. **Construct food web.** Choose a consumable species to cultivate and decide how you will feed it. Find the diagram that corresponds to your species. Cross out any pools in the diagram which will not be in your pond. For example, if you chose chambo, but will not supplement the chambo's diet with fish meal, cross out the box that corresponds to the fish meal pool. Do not cross out algae, zooplankton or detritus, as they will always be present.
2. **Trophic efficiency.** Identify the fluxes (arrows) between organisms representing feeding relationships. Label arrows these arrows with the trophic efficiency at which the organism consumes its food source. Trophic efficiency is the fraction of the foodsource pool that becomes mass in the consumer pool.

$$\text{Trophic efficiency} = \text{consumption} \times \text{assimilation} \times \text{production}$$

3. **Detritus flux.** Identify arrows leading to the detritus pool. Label these arrows with the fraction of a pool's biomass that becomes detritus. Living organisms become detritus if they are not consumed and die or if they are consumed, but are then defecated because they are not assimilated. Hence,  
Fraction that becomes detritus =  $\frac{\text{Fraction not consumed}}{1 - \text{consumption}}$  +  $\frac{\text{Fraction not assimilated}}{\text{consumption} \times (1 - \text{assimilation})}$
4. **Inputs.** The potential inputs to your ecosystem are GPP from algae, fish meal and chicken manure (if you choose to add either of these). Label the production in the pools that each of these inputs affect:

**GPP:** Using Figure 1, label NPP in the algae pool with the rate that corresponds to the amount of fertilizer you choose to add each year. Read the figure caption to determine how to convert the measured GPP to algal NPP. To boost algal production, you may add chicken manure or inorganic fertilizer, but not both. If you do not add any inorganic fertilizer or chicken manure, then NPP of algae will be  $1 \text{ kg m}^{-2} \text{ yr}^{-1}$ .

**Fish meal:** Label the fish meal pool with the amount of fish meal you will supply, if any. Units are in  $\text{kg m}^{-2} \text{ yr}^{-1}$ . That is, the mass of fish meal per  $\text{m}^2$  pond area each year.

**Chicken manure:** Label the detritus pool with the amount of chicken manure you will add to the pond each year (units are  $\text{kg m}^{-2} \text{ yr}^{-1}$ ). The chickens in your village produce a maximum of 1000 kg manure per year. Your pond is  $500 \text{ m}^2$ .

5. **Production.** Use the efficiencies shown in the flux arrows to calculate annual production in each of the pools. For example:



Sometimes the production in a pool will be the sum of two or more fluxes into that pool.

6. **Exports.** Using the annual production of the harvested species, calculate the nutritional services that your pond ecosystem will provide on the worksheet under the diagram.
7. **Optimize production.** Is there anything you can do to increase the harvest rate? Change one aspect of your pond ecosystem and recalculate production of the harvested species. By what percentage did production increase as a result of this change?

8. **Food for thought.** Discuss with your classmates and write a response to one or more of the following questions:

Why did we complete all of our calculations in terms of *production* (e.g. rate of biomass produced) rather than the *amount* of biomass in each pool?

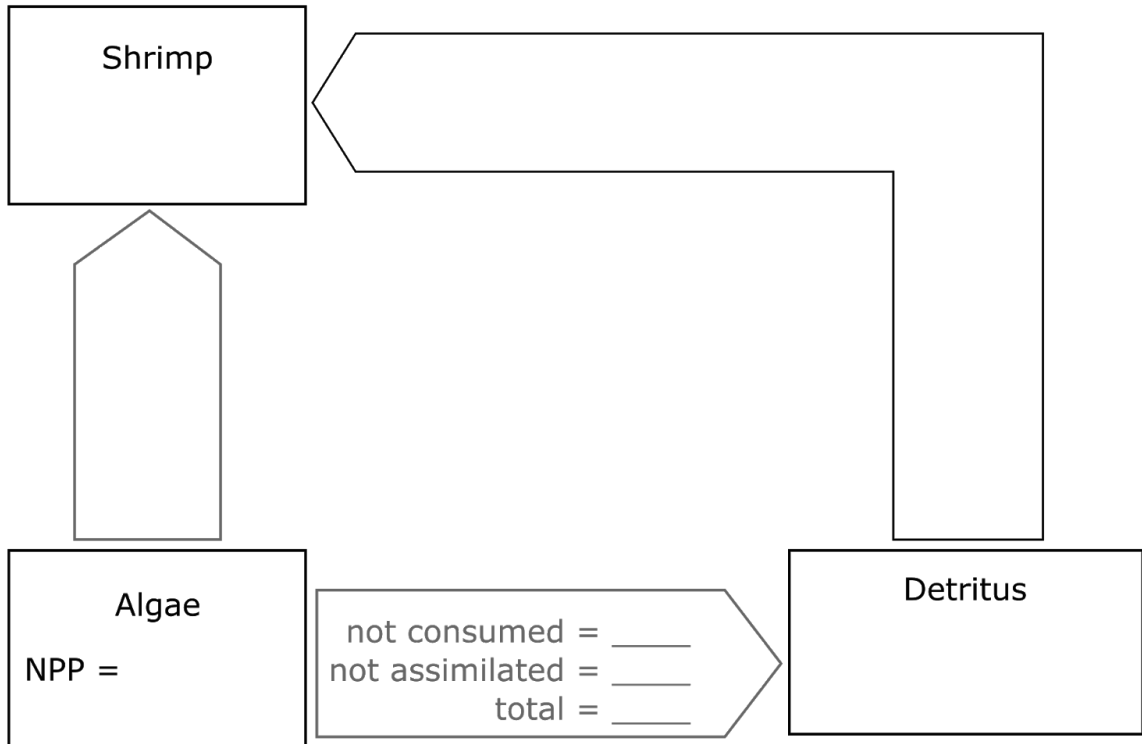
What assumptions have we made in estimating secondary production? What is unrealistic about these assumptions?

What would happen if you recycled the unconsumed portions of your harvest as detritus in the pond?

Other than maximizing harvestable production, what environmental, biological, sociological or economic factors might influence your decisions about how to manage an aquaculture pond?



Annual  
 maximum = \_\_\_\_\_  $\text{kg m}^{-2} \text{yr}^{-1}$   
 harvest



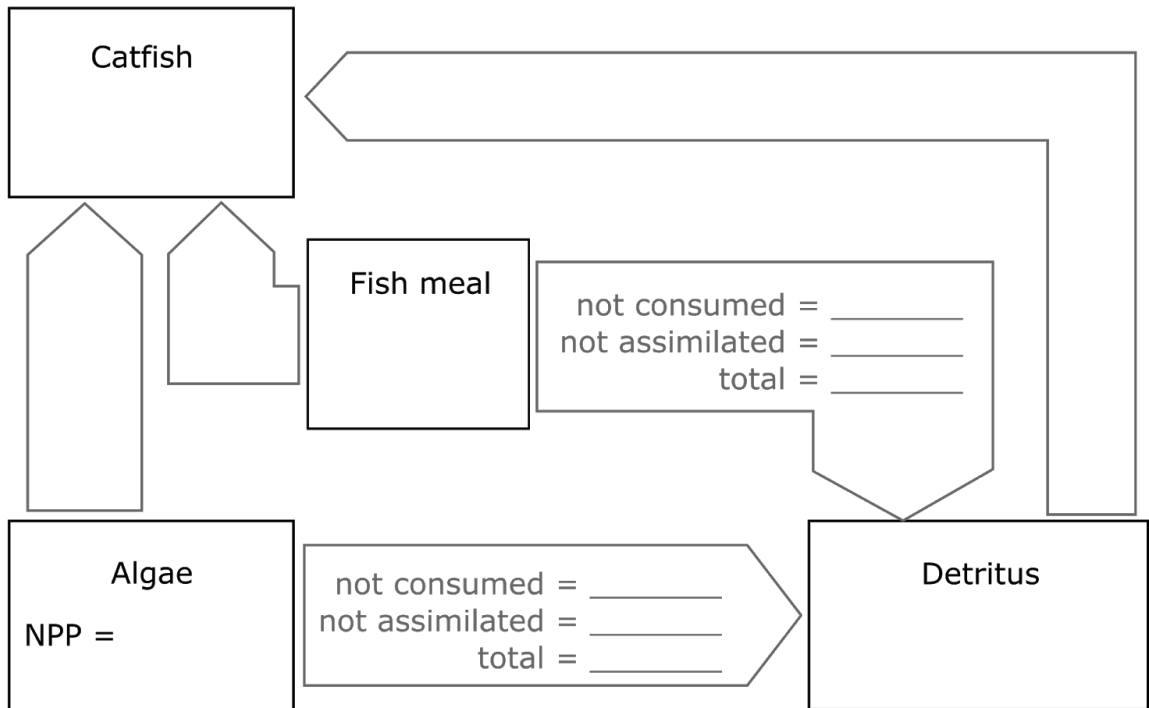
**Harvest species production**

Total annual consumable production: \_\_\_\_\_  $\text{kg yr}^{-1}$

Total annual protein production: \_\_\_\_\_  $\text{g protein yr}^{-1}$

Total annual caloric production: \_\_\_\_\_  $\text{kcal yr}^{-1}$

Annual maximum = \_\_\_\_\_ kg m<sup>-2</sup> yr<sup>-1</sup> harvest



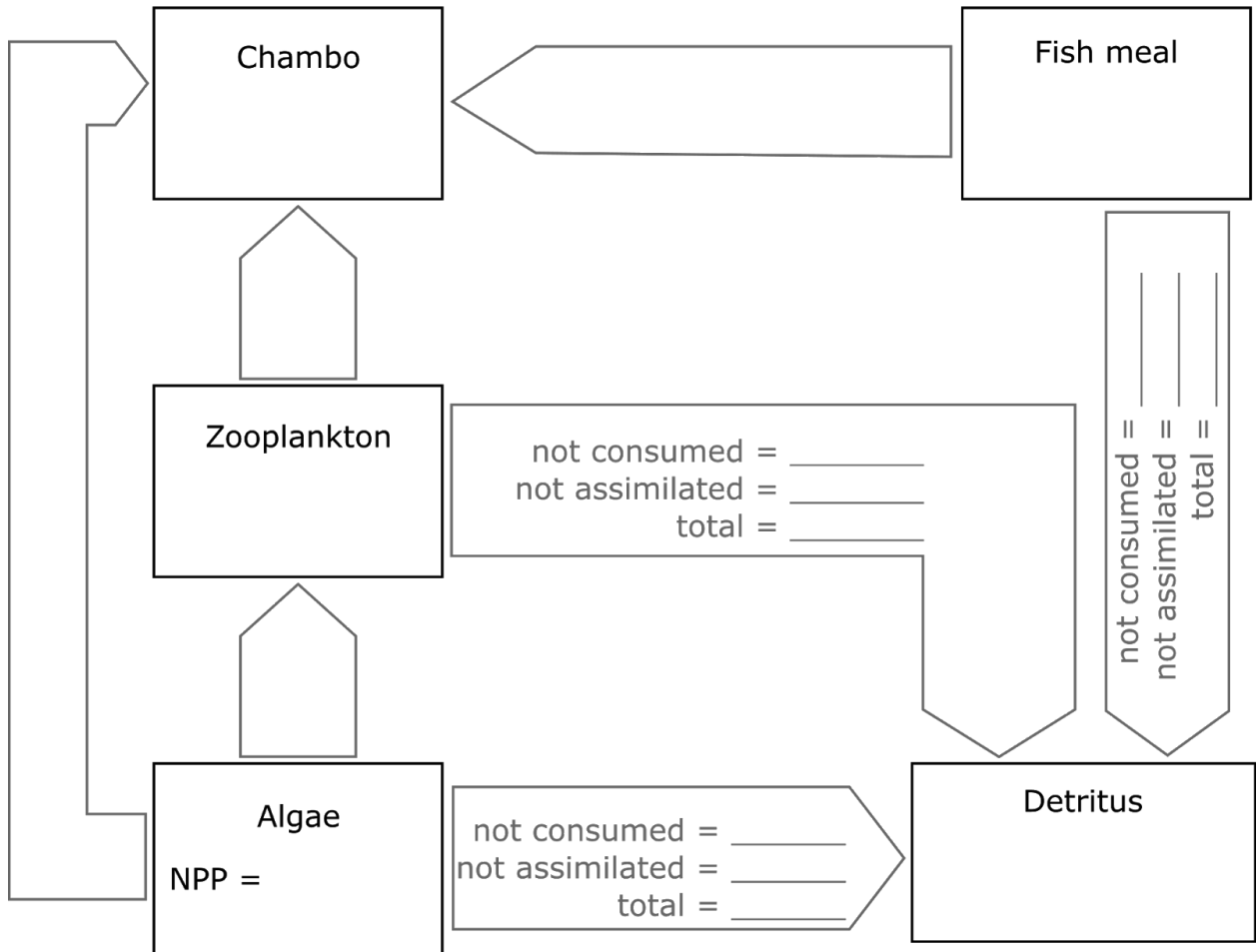
**Harvest species production**

Total annual consumable production: \_\_\_\_\_ kg yr<sup>-1</sup>

Total annual protein production: \_\_\_\_\_ g protein yr<sup>-1</sup>

Total annual caloric production: \_\_\_\_\_ kcal yr<sup>-1</sup>

Annual maximum = \_\_\_\_\_ kg m<sup>-2</sup> yr<sup>-1</sup> harvest



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Total annual consumable production: \_\_\_\_\_ kg yr<sup>-1</sup>

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