# AQUAPONICS CURRICULUM

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Essential Questions:
1. What is the role of oxygen on the uptake of water and minerals?
2. How does transpiration in plants influence fish health in an aquaponic system?

Light & Photosynthesis

Learning Outcome(s):
- Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.
- Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.

Learning Objectives:
1. Evaluate the role of oxygen on the uptake of root water and mineral nutrients.
2. Review of photosynthesis and respiration.
3. Draw connections between root to shoot ratios and nutrient requirements of plants.
4. Analyze the role of transpiration and how to calculate a water transpiration budget and how much make-up water would need to be added to the fish tanks.

Next Generation Science Standards (NGSS):

- LS1 From Molecules to Organisms: Structure & Processes
- LS2 Ecosystems: Interactions, Energy, and Dynamics
- LS4 Biological Evolution: Unity and Diversity
- ESS2 Earth’s Systems
- ESS3 Earth and Human Activity
- PS1 Matter and its Interactions
- PS3 Energy
- PS4 Waves and their application in technology for information transfer
- ETS2 Links among Engineering, Technology, Science, and Society

Seeds need moisture, proper temperature and humidity to germinate. Germination times range between one day and more than a month, depending on the type of plant. Lettuce, bean and pea seeds all germinate rapidly, in a day or two. Tomato and cucumber seeds germinate in 2-4 days.

Although it is possible to seed directly into the aquaponic grow bed, we suggest you set up a separate table for germination. Many growers use a simple flood and drain table, where the water from a reservoir floods the media that the seeds are planted in and then the water drains back to the reservoir. This flood and drain action flushes the media with fresh water and nutrients and then, as it drains away, fresh air is drawn into the cubes. This provides an ideal ratio of water, nutrients and oxygen to the seeds in the media.

The seeds and the space they need for germination is very small, so germinating them in the grow bed is not an efficient use of that space. Once a seedling is 2-3 inches tall, it can be spread out or transplanted into the grow bed. Some growers will transplant the seedlings several times, each time giving the plant more space. This results in the best utilization of the space you have, but requires more labor and handling of the plant.
To germinate seeds that will go into a soilless aquaponic system, most growers will place the seeds in an inert growing medium, such as rockwool or perlite. Other materials that are used include peat moss, a peat moss and vermiculite mix, and coconut coir, which is the shredded husk of coconuts. Ideal mediums are chemically inert, porous, clean, free of contaminants and able to drain freely.

The initial stages of plant growth happen within the seed coat. As the seed absorbs water, growth begins with cell enlargement. In the presence of water, the stored reserves within the seed are converted chemically to substances that can be readily used in the growing process. Once the seed coat breaks and the radicle emerge, the seedling will need to draw moisture and nutrition from the medium surrounding it. The seed itself carries enough nutrients for the germination and the first couple of days of growth. After that, nutrients need to be provided so the plant can grow. Once the first green leaves, the cotyledons, are visible light will be required. If proper light is not provided, a plant will grow tall and spindly; this is often referred to as “stretching.” Young plants will quickly do this without adequate levels of light.

The concept of continuous production in the raft system is to always transplant your seedlings at one end of the raft tank and harvest the mature plants at the other end. The rafts are pushed ahead as rafts with new seedlings are placed in the seedling end, just after mature heads have been removed from the harvest end.

Plants are comprised of major zones that are responsible for specific tasks. Roots anchor the plant and collect water and nutrients. Stems provide support for the leaves which is the primary site for photosynthesis. Collectively, stems and leaves are called the shoot.
The roots serve to anchor the plant into soil or a grow media, but above all they absorb water that is required by the plant for photosynthesis and transpiration. Water absorption occurs mainly in the younger roots or root hairs that expose a tremendous amount of surface area for absorption. Water moves through the roots and into the stem by root pressure. With a high-water potential in the roots and lower water potential in the leaves due to transpiration, water moves by osmosis from the roots to the leaves. The water also carries inorganic nutrients that enter into the roots by active transport. Since nutrients are large molecules, energy is required during root absorption of inorganic nutrients. Once the nutrients are in the plants roots, they are transported by xylem vessels to the leaves.

While water and inorganic nutrients ascend the plants to the leaves, sugars manufactured during photosynthesis move out of the leaves in the assimilate stream of the phloem. The sugars are transported to sites in the plant where they are used, such as growing shoots and roots, but are also sent to sites of storage, such as fruits, seeds, roots and stems.

As the seed embryo develops there is initially a flow of nutrients from the parent plant to the ovule resulting in a buildup of food reserves within the endosperm. Eventually, the ovule becomes a nutritionally closed system and the seed desiccates as it loses water and the seed coat hardens forming a protective armor. The mature embryo consists of one or two cotyledons, which are the seed leaf and often become the first leaves of the plant upon germination. If the embryo has one seed leaf it is called a monocot, such as corn or onions, and if it has two seed leaves it is called a eudicot, such as beans. There is also the epicotyl, or stem above the cotyledons that will eventually develop into the leaves, the plumule or first bud of the plant, the hypocotyl which is the stem located below the cotyledons, and the radicle that will develop into the root.
Germination, or the resumption of growth of the embryo, is dependent on external and internal factors. These factors differ for different plant seeds but external factors can include water, oxygen, temperature and light. Internal factors are triggered by the external factors and this results in the activation of enzymes and a somewhat reversal of what happened when the seed was forming. The stored food in the seed is digested, the cells divide and after the seed imbibes water, it swells, and the seed coat cracks open.

When germination occurs, the first structure to emerge from most seeds is the root or radicle. This allows the seedling to become anchored in the soil or grow media and absorb water. From here, it depends on the species of plant. In some plants, the hypocotyl emerges from the seed bent protecting the shoot tip. Once above ground the cotyledons and plumule are pulled into the air. This type of seed germination is called epigeous.

In other plants, the epicotyl elongates and forms the bent hook. As it straightens out the plumule is raised above ground or above the grow media’s surface. The cotyledons never emerge above the surface. This type of seed germination is called hypogeous.
From here, an orderly sequence of leaves and axillary shoots develops into the full plant. Germination and the development of the embryo into a plant is the most crucial phase in a plant's development and is when the plant is most susceptible to injury from disease, insect pests and fungi.

**Activity 9: Seeding, Development & Transplanting**

**Activity Learning Objectives:**
- Observe differences in germination rates and development with seeds planed in different media.
- Observe prepared microscope slides, or online pictures ([http://biology.kenyon.edu/courses/biol114/Chap12/Chapter_12A.html](http://biology.kenyon.edu/courses/biol114/Chap12/Chapter_12A.html)), to show early cell development, embryogenesis, cell division and organogenesis.
- Practice transplanting seedlings from the germination tray to the raft, NFT and media beds.

**NGSS Practices:**
1. Asking questions
2. Conducting Investigations
3. Analyzing Data
4. Using Mathematics
5. Constructing Explanations
6. Communicating Information

**Estimated Time:**
- Discussion: 30 minutes
- Activity: 30 minutes
- Observations: Several Days

**Activity Objectives:**

**Materials (for activities 2-4)**
- Variety of media (rock wool, sand, gravel, perlite, clay balls, coconut coir)
- plastic net cups
- seeds of monocots and eudicots
- seeding sticks
- prepared slides of early plant development
- aerator with air stone
- celery
- food coloring
- plastic cup
- knife
- plastic bags
- twist-ties
- rulers
- balance
**DIRECTED INSTRUCTIONS:**

1. Place seeds in a variety of media in a germination table and observe differences in germination and early plant development. For example, media may consist of rock wool, sand, gravel, perlite, clay balls, and coconut coir.

2. Qualitatively describe root and shoot formation based on density and porosity of media. Note: some loose media may require net pots (https://aquaponics.com/store2/2-net-pots/).

3. Over several days observe and document plant development comparing prepared slides or online pictures to live seedlings. If microscopes are available, view early stages of plant development including radicles, cotyledons, epicotyl and hypocotyl.

4. Discuss role of each part including nutrient reservoirs, first emergence (epigeous and hypogeous) and initiation of photosynthesis.

5. After 1-2 weeks, transplant the seedlings from the germination tray to the grow bed. This is a good time to take notes on plant development, maturation and health. While you may have only one type of grow bed, typically a raft or deep-water culture, take the time to discuss other types of grow bed systems such as raft (DWC), nutrient film technique (NFT) and media beds.

6. Discuss the type of plant you can grow in each grow bed, nutrient uptake and plant architecture.

Generate a table that compares and contrasts the differences in transplanting and selection of a grow bed such
Table 13. Comparison and contrast between grow beds

<table>
<thead>
<tr>
<th>Grow Bed</th>
<th>Advantage</th>
<th>Disadvantage</th>
<th>Nutrient uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raft¹</td>
<td>Constant water flow</td>
<td>Biofilter may be needed</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Small sump needed</td>
<td>Large volume of water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Easy maintenance &amp; cleaning</td>
<td>Root aeration needed</td>
<td></td>
</tr>
<tr>
<td>Nutrient Film Technique²</td>
<td>Constant water flow</td>
<td>Biofilter needed</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Small sump needed</td>
<td>Lower yield</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Smaller water volume</td>
<td>Less system stability</td>
<td></td>
</tr>
<tr>
<td>Media-based</td>
<td>Biofiltration in media</td>
<td>Large sump needed</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Solids filtered in media</td>
<td>Maintenance &amp; cleaning difficult</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mineralization in grow bed</td>
<td>Clogging can lead to channelization</td>
<td></td>
</tr>
</tbody>
</table>

**ACCOMMODATIONS & GRADE/LEVEL DIFFERENTIATION:**
Provide students with illustrations and written directions. Allow students more time to devise their experiment (e.g. assign experimental design as a homework assignment). Provide diagrams of the germination process, photosynthesis and plant anatomy.
Activity 10: Plant Physiology

Activity Learning Objectives:
1. Evaluate the role of oxygen on the uptake of root water and mineral nutrients. Review of photosynthesis and respiration.
2. Observe water and nutrient movement as seen through celery (https://www.instructables.com/id/Observing-Water-Movement-Within-Celery/) to show xylem and phloem tissue and capillary action.
3. Compare root to shoot ratios and evaluate how they indicate nutrient requirements of plants.
4. Describe the role of transpiration and calculate a water transpiration budget and how much make-up water would need to be added to the fish tanks.
5. Recognize the basic procedures of photosynthesis, transpiration and the influence of light spectrums

NGSS Practices:
1. Asking questions
2. Conducting Investigations
3. Analyzing Data
4. Using Mathematics
5. Constructing Explanations
6. Communicating Information
7. Arguing from Evidence

Materials:
- Grow bed with actively growing plants
- Airstone
- Celery
- Food coloring
- Plastic cups
- 3 plastic bags
- Scale
- Twist ties
- Variety of lighting condition (The source of the light can come from the sun (if the garden is near a window or in a greenhouse), fluorescent, incandescent, metal halide or high-pressure sodium lights. Light levels can be increased by use of a light reflector)

Directed Instructions:
Exercise 1: Aeration of the roots is important for plants to uptake water and mineral nutrients.
1. To test this, using a raft grow bed, fix an airstone to the bottom of the grow bed so that only some of the plant roots are coming into direct contact with the air bubbles.

2. Over the course of a few weeks count the number of leaves on each plant, measure the maximum shoot height and leaf canopy width, and the length of the roots.

3. Plot the growth of the plants based on average length & number of each variable over the course of time for plants directly and indirectly in contact with the air bubbles.

**Exercise 2:** Differences in xylem and phloem tissue can be seen by performing a simple experiment with celery. While you can use celery, you may be growing in your aquaponics system, the experiment works fine with previously harvested, store bought celery (whole not hearts).

1. Using a knife, cut the celery into 3 pieces about 6 cm long. Each piece should be cut differently (e.g. 1. Include leaves, 2. Cut evenly on both ends, 3. Cut unevenly with some of the skin of the celery separated from the rest of the celery).

2. Measure ¼ cup water into a clear plastic cup

3. Add three drops of food coloring into the cup filled with water. Mix.

4. Place the celery in the cup of water vertically so that only one end of the celery is in the water.

5. Allow celery to sit for at least 6 hours.

6. Make observations.

**Exercise 3:** Roots allow plants to absorb water and mineral nutrients from the water and a healthy root system is the key to a healthy plant. The root:shoot ratio is one measure to assess the overall health of your plants. A healthy plant should have an even balance of root and shoot biomass (close to 1:1). Any deviations from this (either up or down) would be an indication of a change in the overall health of your plant. It is important to combine data from the root:shoot ratio with data from observations to get an accurate understanding of what is happening to the plants. For example, an increase in root:shoot ratio could be an indication of a healthier plant, provided the increase came from greater root size and not from a decrease in shoot biomass. Overall, long roots and short shoots suggest a plant is searching for nutrients in a nutrient poor environment while long shoots and short roots indicate adequate growth and nutrient availability (https://www.sciencebuddies.org/science-fair-projects/references/measuring-plant-growth).

In aquaponics, water loss not only occurs from evaporation from the fish tanks, but also through plant transpiration. A corresponding and appropriate amount of “make-up” water may need to be added to the system daily. This water should be of proper quality and consistency.
with the current water in the system (i.e. not chlorinated, equal temperature, pH, etc). To better understand the potential water loss due to transpiration, this simple experiment can be conducted.

1. Take three plastic bags, label and weigh each in its empty state.
2. Place one bag each on the plants in the raft grow bed. The bag should be placed loosely over the plant but use a twist-tie to wrap the bag about the base of the stem of the plant securely, thereby, closing the bag.
3. Wait 1 hour (if sunny, 2 hours if cloudy), then gently remove the bag from the plant, which may require tilting the plant, being careful not to allow any water in the bag to drip out.
4. Reweigh the bag with the water contained within. The weight difference between the empty plastic bag and the bag with the condensation will be the transpiration amount (grams of water per hour).

5. Calculate water transpiration budget by multiplying the amount of water transpired per hour for the plant you measured, times the total number of plants in your grow bed system, times the number of hours of daylight. Water loss due to transpiration is greatly reduced at night when the plants respire. This calculation should provide you with an estimate of the amount of make-up water that would need to be added daily to the fish tanks due to transpiration alone. To make the estimate slightly more accurate, you can double or halve the transpiration amount based on the size of the plants in the system compared to the size of the plant you actually measured.

**EXTENSION ACTIVITY:**

Compare sugar production by different plants in your system. If you recall, photosynthesis is the process of converting the sun’s light into chemical energy and storing this energy in the bonds of sugar. This sugar ultimately forms the building blocks for fats, proteins starches, cellulose, etc. To measure the amount of sugar in a plant we will use a tool known as a refractometer. A refractometer measures the amount of sugar as degrees of Brix. High levels of brix can be used as a proxy for higher rates of photosynthesis. To conduct this test, you need a few drops of juice from the leaves of your plant. Place this liquid into the refractometer and hold it up to the light. The light passing through the liquid will refract (bend) based on the contents of the liquid (how many dissolved solids such as sugar, minerals, proteins, etc.). Record your reading in degrees of Brix.
QUESTIONS FOR DISCUSSION:

1. Describe the process of transport through the celery plant. Discuss the action and role of capillary action.

2. Discuss the role of air in the uptake of water and mineral nutrient movement by osmosis and active transport.

ACTIVITY GUIDELINES/TIPS:

A review of photosynthesis and respiration should precede these exercises (See review/assessment that follows).
Chloroplasts
Photosynthesis is a process in which sunlight energy is used to make glucose. The site of photosynthesis is in the chloroplast – an organelle found in the leaves of green plants. The main functions of chloroplasts are to produce food (glucose) during photosynthesis, and to store food energy. Chloroplasts contain the pigment, chlorophyll. Chlorophyll absorbs most of the colors in the color spectrum and reflects only green and yellow wavelengths of light. This is why we see leaves as green or yellow – because these colors are reflected into our eyes.

Plant Cell

1. What is photosynthesis? Process by which plants make their own food (glucose) and produce oxygen

2. Where does photosynthesis occur? In the leaves of plants in structures called chloroplasts

3. What are chloroplasts and where are they found? Organelles found in the leaves of green plants

4. What are the two main functions of chloroplasts? To produce glucose and food energy

5. Why do most leaves appear green? Because of the pigment chlorophyll found in the chloroplast

6. What is the primary pigment found in the chloroplast? Chlorophyll

Photosynthesis
Glucose is another name for sugar. The molecular formula for glucose is C₆H₁₂O₆. Plants make sugar by using the energy from sunlight to transform CO₂ from the air with water from the
ground into glucose. This process, called photosynthesis, occurs in the chloroplast of the plant cell. During this process, oxygen (O₂) is created as a waste product and is released into the air for us to breathe. The formula for photosynthesis is:

\[ \text{CO}_2 + \text{H}_2\text{O} + \text{sunlight} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \]

This formula says that carbon dioxide and water molecules are combined with the energy from sunlight to produce sugar and oxygen. The reactants in photosynthesis (what is used) are CO₂, water and sun. The plant gets water from the ground through its roots. The plant collects carbon dioxide from the air. Much of the carbon dioxide comes from living organisms that exhale it, but some also comes from factory smokestacks and car fumes.

7. What is the formula for photosynthesis?  
   \[ \text{CO}_2 + \text{H}_2\text{O} + \text{sunlight} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \]

8. What three things are used to make glucose in photosynthesis?  
   Light energy, carbon dioxide, and water

9. Where does the water come from? From the ground

10. Where does the water enter the plant? Roots

11. What are some sources of CO₂? Living organisms, smokestacks, and car fumes

12. What type of energy does the plant use to convert CO₂ and H₂O into sugar?  
   Light energy

13. What two major plant processes require light:

   The products (what is made) are glucose and oxygen. The glucose produced is used by the plant for energy and growth. We also use this glucose by eating plants. The oxygen
produced is released into the air for us to breathe. Photosynthesis is essential for all life on earth, because it provides food and oxygen.

14. What is produced in photosynthesis? **Glucose and Oxygen**

15. What is the glucose used for? **Energy and growth**

16. What is the oxygen used for? **For living organisms to breathe**

**Cellular Respiration**

Respiration is the cellular process in which glucose breaks down into water and carbon dioxide and releases energy.

\[
\text{Glucose} + \text{Oxygen} \rightarrow \text{Carbon Dioxide} + \text{water} + \text{Energy (ATP)}
\]

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Energy (ATP)}
\]

Respiration can occur without light because energy is stored in carbohydrate molecules. Respiration occurs in **both plant and animal cells** in structures called **mitochondria**.

**TRUE/FALSE**

17. The transpiration process stores energy for other plant processes.
   True / False

18. Photosynthesis takes place in the chloroplasts within the leaf tissue.
   True / False

19. The orange rays are the longest rays of sunlight.
   True / False

20. Incandescent light is very effective for plant growth. True / False

21. List the four primary types of supplemental light:
   a. incandescent
b. fluorescent

c. metal halide

d. high pressure sodium

1. What is cellular respiration? Cellular process in which glucose is broken down into carbon dioxide and water, and energy is released

2. Where does cellular respiration occur? Occurs in both plant and animal cells in structures called mitochondria

3. What is the formula for cellular respiration? 
   \[ C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy(ATP)} \]

4. What are the products of cellular respiration? Carbon dioxide, water and ATP energy
Aquaponic systems must operate near maximum fish production capacity, also called **loading density**, to be economical. Therefore, fry or fingerlings should be stocked at very high rates at around 30 fish per cubic foot. Feeding rates should be at optimum for rapid fish and plant growth while also making sure not to overfeed.

Loading density, or **carrying capacity**, is the number or biomass of fish an aquaponic system can support. In a recirculating system, the loading density depends on water flow, volume, exchange rate, temperature, dissolved oxygen, pH, size and species of fish, and the accumulation of metabolic waste. Since dissolved oxygen is affected by temperature, is directly related to metabolism, its quantity is a function of water volume, and its regeneration is dependent on the water exchange rate, it is often used as the limiting factor when determining loading density. But the general rule is that whatever the **limiting factor** is, it is used to determine the loading density of fish in the system.

The loading density of a system is usually stated as the pounds of fish per cubic foot of water. Catastrophic fish losses can be caused by overloaded tanks and systems and it is important to remember that the loading...
Density needs to be continuously calculated as the fish grow since the biomass of fish is increasing as they grow. But fish density can often be increased as fish size increases, yet this has to be balanced against the fact that as density increases so may crowding of the fish which can affect their growth rate.

There are a variety of ways to calculate the fish loading density for your system. Here we will cover two different methods. The first is based on the length of the fish and unit volume of water for the fish. One drawback to this formula is that the value \( C_{\text{density}} \) has only been determined for a few species of fish. The second method, can be applied to most any species of fish, but has more factors you'll need to enter. In the first equation, you need to know the average length of the fish you have and use the \( C_{\text{density}} \) value that was developed based on prior research. When measuring the length of a sample of your fish you should also calculate the standard deviation of the sample. The length of all the fish you measure should not vary by more than 10% from the average. If they do, this is indicative of over-stocking, under feeding, or other management problems and will provide an inaccurate value for the loading density.

\[
D_{\text{density}} = \frac{L}{C_{\text{density}}}
\]

Where:

\( D_{\text{density}} = \) density in kg/m\(^3\) (mass of fish per unit volume)
\( L = \) average length of fish in cm
\( C_{\text{density}} = \) (for tilapia = 0.24); (for trout = 0.32); (for perch = 0.40)

An example of loading density calculations for tilapia and trout would look like:

<table>
<thead>
<tr>
<th>Length (cm)</th>
<th>Weight (g)</th>
<th>Fish/m(^3)</th>
<th>Kg/m(^3)</th>
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<tbody>
<tr>
<td><strong>Tilapia</strong></td>
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<tr>
<td>2</td>
<td>0.2</td>
<td>41,667</td>
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<tr>
<td>12</td>
<td>19</td>
<td>1,974</td>
<td>37.5</td>
</tr>
</tbody>
</table>
Trout | 15 | 37 | 1,267 | 46.9  
| 20 | 89 | 702  | 62.5  
| 25 | 173| 452  | 78.1  
| 30 | 299| 314  | 93.8  
| 35 | 475| 230  | 109.4 

And, graphically it would be presented as:

![Graph](image_url)

In general, it is recommended that if you are raising tilapia in an aquaponic system the fish loading density should not exceed 60 kg/m³. This density has been shown to promote fast growth and efficient feed conversion and reduce crowding stress that may lead to disease outbreaks. But it is based on a system where tilapia grow at a high density with consistently good water quality, higher water exchange rates, and vigorous aeration that provides DO that stays at 5-6 mg/L.

The formula for **standard deviation (SD)** is:

\[
SD = \text{square root } \left[ \text{Sum (x – X)}^2 / (n-1) \right]
\]

Where:
\[
\begin{align*}
x &= \text{number} \\
X &= \text{mean (average) of the numbers} \\
n &= \text{number of numerical entries}
\end{align*}
\]

Here is a second method for calculating loading rate. The amount of fish kept in the tank can never be greater than the **single limiting factor** that is, the factor in short supply, that the
system provides. Since ammonia is toxic to fish at low levels, we can use total ammonia in this example. The following formula is one way to calculate the density of fish that the system can handle based on total ammonia nitrogen being the limiting factor.

The formula is a two-step process. First, you establish what conditions are in your system and then, you determine the density of fish that would push your system beyond safe limits for total ammonia nitrogen (TAN). For step one, determine the Ammonia factor for the fish tanks in the aquaponic system:

\[
\text{Ammonia factor} = \frac{[(\text{total ammonia}) \times (\text{flow rate})]}{\text{(weight of food fed per day)}}
\]

- Total ammonia in mg/L
- Flow rate in gallons per minute
- Weight of food in pounds per day

Remember, if your aquaponic system has multiple fish tanks you must determine the average total ammonia nitrogen among the fish tanks, the total flow rate (add together the flow to each tank), and the total weight of fish food given to all the tanks daily. Once calculated, this is the Ammonia factor for the entire system.

In this method, the loading density is based on the amount of fish food added to the system daily. Since the primary source of ammonia is the metabolism of food by the fish, there is a correlation between the amount of fish food and the biomass of fish. So, in the second step to this method you obtain from published scientific literature what the maximum tolerance level of total ammonia nitrogen is for your fish (Note: this is TAN not just unionized ammonia). Then, you rearrange the previous formula to:

\[
\text{Total ammonia} = \frac{[(\text{weight of food fed per day}) \times (\text{ammonia factor})]}{\text{(flow rate)}}
\]

Then you empirically calculate how much food you can add to your system until the calculated total ammonia nitrogen exceeds the maximum tolerance level you obtained from published scientific literature. As long as you keep the feeding rate the same, the ammonia level will only rise based on the increases in feed provided to the loading density of fish. The method is a bit “trial and error” but it establishes an Ammonia factor and loading density specific to your aquaponic system. For example:

An aquaponic facility determines that the total ammonia nitrogen in its fry culture tanks is 0.70 mg/L. The system has a flow rate of 5 gallons per minute and the fry are fed 0.40 pounds of food per day. This results in an Ammonia factor = 8.75. The published scientific literature says that the maximum tolerance level of total ammonia nitrogen for most fish is 1.0 mg/L. Using the second formula:
Total ammonia = \((0.60 \text{ pounds of food per day}) \times 8.75\) / (5 gpm) = 1.0 mg/L TAN

Therefore, the amount of feed provided to the fish can increase from 0.4 to 0.6 pounds of food per day. Accordingly, you would add additional fish to the system if you keep the feeding rate at the same amount. So, if you had 128 fish in the tanks and each fish had an average weight of 0.11 pounds (50 grams) and you fed the fish at 3% body weight per day, you would be able to increase the number of fish in the system to 181 fish and stay at or below the maximum tolerance level of total ammonia nitrogen.

(Math breakdown: 14.1 pounds of fish (6,400 grams) fed 3% body weight per day would get fed 0.4 pounds of food per day (192 grams/day). If each fish had an average weight of 0.11 pounds (50 grams) and you increased the amount of feed to 0.6 pounds (272 grams), then you could have a total biomass of fish of 20 pounds (9,067 grams) or 181 fish.)

**Growth**

The growth rate of a fish depends on many factors such as diet, care, strain, species, and the water temperature. Knowing the growth rates of fish will help in determining culture tank density, water flow and production goals. Using growth rate as a projection can also help when determining feed orders and tank stocking dates.

One way to predict the growth of fish is to calculate the specific growth rate. Use of the formula is fairly straightforward. You need to measure the weight of a sample of fish on some date, indicated at \(t_1\), and then measure the weight of a sample of fish again at a later date, labeled \(t_2\). This will help you to determine the growth rate during this time period.

\[
G = \left[\frac{\ln W_2 - \ln W_1}{(t_2 - t_1)}\right] \times 100
\]

Where:

- \(G\) = specific growth rate (% per day)
- \(W\) = weight at times 1 (\(W_1\)) and 2 (\(W_2\)) in grams
- \(t\) = initial (\(t_1\)) and time passed (\(t_2\)) in days

There are a variety of ways to predict fish growth and they all depend on what information you have available. Another way to predict the growth of fish in a closed, recirculating system with constant temperature is to base growth on some defined number of temperature units to
create a unit of growth. In the equation shown, growth is measured as cm per month and assumes that you feed the fish a constant percentage of feed.

\[ G = \frac{(T - T_{\text{base}})}{T U_{\text{base}}} \]

\( T = \) the constant temperature in your system

\( T_{\text{base}} \) and \( T U_{\text{base}} \) are based on historical observations and numerous facility records. One precaution, if the temperature in your system is greater than \( T_{\text{max}} \), then calculate the growth at \( T_{\text{max}} \), but the excessive temperature will compromise growth and/or feed conversion.

<table>
<thead>
<tr>
<th></th>
<th>Trout</th>
<th>Tilapia</th>
<th>Perch</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{\text{base}} )</td>
<td>0 (32)</td>
<td>18.3 (65)</td>
<td>10 (50)</td>
</tr>
<tr>
<td>( T U_{\text{base}} )</td>
<td>6.12 (28)</td>
<td>3.28 (15)</td>
<td>5.47 (25)</td>
</tr>
<tr>
<td>( T_{\text{max}} )</td>
<td>22.2 (72)</td>
<td>29.5 (85)</td>
<td>23.9 (75)</td>
</tr>
</tbody>
</table>

Temperature growth units for trout, tilapia and perch, °C (°F)

For example, if you are raising tilapia with a constant water temperature of 26.7°C or 80°F, then the equation would show 26.7 minus 18.3, divided by 3.28; that results in 2.56 cm of growth per month.

The disadvantage to using this equation is that the temperature units shown in the table have only been published for a few fish species. If you are raising a fish for which the values have not been determined – then either you can’t use this particular method or you would have to figure out the values by “trial and error.”

Growth can be projected if the average monthly temperature and increase in fish length are known for several months. The Monthly Temperature Unit (MTU) required per inch of growth must first be determined. MTU’s are the average water temperature for a one-month period, minus 32°F. Thus, a culture tank with a monthly average water temperature of 50°F would have 18 MTU’s available for growth; that is 50 – 32 = 18. To determine the number of MTU’s required for one inch of growth, the MTU for the month is divided by the monthly gain in inches (available from records on fish growth you’ve been keeping).

\[ \text{MTU} = \frac{\text{average water temperature for a one-month period (minus 32°F)}}{\text{MTU required per inch of growth}} \]

\[ \text{Monthly growth (inch)} = \frac{\text{MTU for the month}}{\text{MTU required per inch of growth}} \]

For example: Let’s say a culture tank had a temperature of 59°F. It would have 27 MTU’s or 59 – 32. If the fish grew 2.5 inches over the course of the month, the fish would show 10.8 MTU per inch of growth; or 27 / 2.5.
Once the number of MTU’s required for one inch of growth is determined, the expected growth for any month can be calculated using the equation shown.

For example: From past records you’ve kept it was determined that 27 MTU’s were required per inch of growth and the average water temperature for the month of August was expected to be 70°F. What length increase can be expected for the month of August?

Since the MTU’s available during the month of August will be 38 or 70 – 32. And you know that 27 MTU’s are required for one inch of growth, the projected increase for August is 1.4 inches or 38 divided by 27. If the fish in the tank were 3.41 inches on August 1, then they will be 4.81 inches or 3.41 + 1.4, at the end of August.

**ANATOMY**

Now let’s shift from growth to the anatomy of a fish. Fish have a very basic external anatomy. Most fish’s bodies are covered in scales, of which there are different types associated with different species of fish that protect the fish from diseases, physical damage, and aid in the hydrodynamics of swimming. Their skin acts as a barrier between the fish’s organs and the environment, but can also be used by the grower, or consumer, as an indication of freshness. Fish are also covered in a slime coat that is part of their immune system, just like the mucus in our nose, that also aids in the hydrodynamics of swimming.

**External Anatomy**

- Scales = Defense + hydrodynamics
- Skin = Protection + freshness
- Slime coat = Immunity + hydrodynamics
- Eyes
- Nose
- Ear
- Lateral line
Now let’s move to the inside of the fish. Fish have **digestive systems** that are generally similar to other simple-stomached animals. The mouth is used to capture food and most food is gulped and swallowed intact. Some fish can bite their food into smaller pieces, while others have pharyngeal teeth, located in the throat, that are used to grind food. After food is swallowed, it enters the stomach where digestion begins with the addition of enzymes and hydrochloric acid. Very little nutrient absorption occurs in the stomach. Fish with small or no stomach, such as carp, begin digestion in the intestine. Then, food leaves the stomach and enters the pyloric ceca and intestine, where it is enzymatically broken down into basic components that are absorbed and utilized. The pyloric ceca is a primary source of digestive enzymes that break down complicated chemical components into basic components such as protein into amino acids, lipids into fatty acids, and starch or carbohydrates into simple sugars. Nutrients that cannot be utilized are held in the distil region of the intestine until they are expelled as feces.

The **circulatory system**, or basic pattern of blood flow in most fishes, involves a two chambered heart-pump, single-circuit system where blood flows from the heart to the gills to the body and back to the heart.
The **swim bladder** is a gas-filled sac located between the alimentary canal and the kidneys. It is filled with carbon dioxide, oxygen, and nitrogen gases. It functions mainly as a hydrostatic organ that helps control buoyancy and also plays a role in respiration, sound production, and sound reception in some fishes.

The **kidneys** are paired longitudinal structures located outside of the peritoneal cavity, which contains most of the other organs, underneath the vertebrate. Left and right kidneys are usually joined together and form a reddish-black material under the vertebrate running from the back of the skull to the end of the body cavity. The primary function is excretion and osmoregulation. Urine in freshwater fishes contains water plus creatine, creatinine, urea, ammonia, and other nitrogenous waste products. Only 3% - 50% of nitrogenous waste is excreted through urine with the rest excreted as ammonia across the gills. Freshwater fishes excrete highly dilute urine composed mainly of water, while marine fish excrete highly concentrated urine that has very little water.

The **liver and pancreas** both aid digestion, with the gall bladder acting as a storage site for bile. The liver also stores fat in some fishes. The pancreas also acts as an endocrine organ producing different hormones.

The **spleen** has an important role in the fish's immune system where it produces macrophages as part of an immune response; therefore, the spleen is often examined by veterinarians when it is believed that a disease is present or if a fish looks sick.
ACTIVITY 11: FISH DISSECTION

ACTIVITY LEARNING OBJECTIVES:

- Understanding the internal organs and system functions of a local fish species
- Understand the external body parts of fish
- Discuss both internal and external features in relation to the human anatomy.
- Identify 3-5 external anatomical features of a fish.
- Identify the major internal organs of a fish.
- Compare and contrast human and fish internal organs, structures, and systems.
NGSS Practices:
Conducting Investigations

Estimated Time:
Discussion: 30 minutes
Activity: 1-3 days depending on numbers structures to be identified.

Materials
- 2 Fish for dissection
- 2 scissors, scalpels, filet knives, or dissecting kits
- 2 dissecting trays or cutting boards
- Organ definition cards
- Hand sanitizer
- Laptop computer & projector
- Fish mounts, models or pictures
- Newspaper or protective table cover, 2 or more rags
- Box of plastic gloves (non-latex)
- Dissection Power Point presentation
- Dissection Worksheet
- Internal Anatomy Crossword Puzzle

Directed Instructions:
1. Study the external anatomy and specific body parts of the fish in your aquaponic system.
2. Observe and discuss the functions of specific fins and other external parts.
3. Dissect fish in groups of two following instruction.
4. Compare humans and other more complex beings to fish.

Activity Guidelines
Establish two dissection stations – tables with covering (i.e. newspaper or plastic). At each table, have necessary dissection equipment as listed in Materials above. A Power Point presentation will review basic external fish anatomy and introduce the internal anatomy of humans and fish. Have students explain how/why external features relate to fishing (e.g. Protection: sharp fins, teeth, slime layer. Speed, camouflage. Where to target fish in water column? What fishing techniques to use; e.g., rig, etc.).

Split the class into two equal groups. During the dissection, have interested students put on gloves and identify organs. Have students read organ definition cards out loud. Tell students they will be playing a game based on this lesson plan at which time they’ll be responsible for both the form and function of the internal structures.

Reinforcement of Fish Anatomy Game
Tell students that each dissection group will compete with each other in a game. Give
directions to the game and answer any questions.
1. Select a member from each team to serve as the team representative.
2. Project a question from the PowerPoint and have teams discuss possible answers. Then have the team representatives each state a response aloud; the first team to correctly answer the question receives a determined number of points. The team with the most points at the end of the game wins.
3. At the end, determine the winner. (Tip: Consider offering the winning team a small treat or prize.)

**Fish Identification**
1. If time permits, use fish models or pictures to help students identify fish that may be found during the upcoming fishing trip.
2. Re-iterate anatomical features and relationship to fishing.

**Accommodations & Grade/Level Differentiation:** Advise students to also view PowerPoint during dissection period. (Tip: This is especially helpful for those students resisting participation.)

---

**UNIT 10: Fish Dissection Assessment**

1. Identify 3-5 external anatomical features of a fish.

2. Identify a few major internal organs of a fish.

3. Compare and contrast human and fish internal organs, structures, and systems.

4. What is the function of a swim bladder, and how does it work?
   Only found in “ray-finned” fish, the swim bladder is a gas-filled sac, assisting with maintaining neutral buoyancy. In some fish, also assists in better hearing due to proximity to otoliths.

5. What is the purpose of the Lateral Line?
   To sense vibrations in the water, as well as, changes in water pressure.

6. How does the Heart differ between humans and fish?
   Humans have a 4-chambered heart increasing efficiency of oxygen delivery, while fish have just 2 chambers.
Human circulatory system is a double circuit (heart → lungs → heart → body → heart).
Fish circulatory system is a single circuit (heart → gills → body → heart).

7. Name two organs fish have that humans do not.
   Gills, Lateral Line

8. A dorsal fin lends stability in swimming. True / False

9. The skin of a fish has two layers, the epidermis and the dermis. True / False

10. The Pelvic fin is located just below the gills. True / False

11. Respiration is carried out in the gills. True / False

12. The scales of a fish lie in pockets in the Dermis and come out of connective tissue. True / False

13. The Lateral line is a part of the sensory system. True / False

14. The sense of smell is highly developed in fish and probably used more than the sense of sight. True / False

15. Fish possess an internal skeleton and oysters possess an external skeleton. True / False

16. List five of the nine body systems in aquatic animals:
   a. Circulatory
   b. Digestive
   c. Excretory
   d. Muscular
   e. Nervous
   f. Reproductive
   g. Respiratory
   h. Sensory
   i. Skeletal

17. The circulatory system distributes blood to the body.
   a. carbon dioxide
   b. blood
   c. ammonia
   d. oxygen
18. List three body systems that both humans and fish have.

19. Draw a line and match each fish organ/body part to its appropriate function.

<table>
<thead>
<tr>
<th>Gill</th>
<th>Protects fish from parasites and bacteria in the water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Line</td>
<td>Filters toxins from a fish's blood stream and creates waste</td>
</tr>
<tr>
<td>Spleen</td>
<td>Filled with gases; helps the fish move up and down in the water column</td>
</tr>
<tr>
<td>Swim Bladder</td>
<td>Helps with digestion processes</td>
</tr>
<tr>
<td>Kidney</td>
<td>Allows the fish to hear and feel vibrations in the water</td>
</tr>
<tr>
<td>Pyloric</td>
<td>Secretes bile to aid in digestion</td>
</tr>
<tr>
<td>Liver</td>
<td>Allows fish to breathe underwater</td>
</tr>
</tbody>
</table>

20. Label the external anatomy of the fish found in the Porgy family.

(Reprinted from NYSDEC Region 1 Freshwater Fisheries I Fish NY Program; https://www.dec.ny.gov/docs/administration_pdf/ifnyfdlp.pdf)
VOCABULARY

- **Anal Fin** - fin located near the anal opening; used for balance and steering.
- **Caudal or Tail Fin** - fin at the tail of a fish; used for propulsion.
- **Circulatory System** - delivers blood and oxygen throughout the body via the heart.
- **Digestive System** - breaks down and processes proteins, carbohydrates and fats.
- **Dorsal Fin** - backside (top) fin on a fish; used for balance and protection.
- **External Anatomy** - the outside body parts, such as, fins, scales, mouth.
- **Gills** - organ used to obtain oxygen from the water and rid carbon dioxide.
- **Gill Rakers** - filter feed tiny prey; appendages along the front edge of the gill arch.
- **Gonads** - the sex organs; males have testes, females have ovaries. Some fish are hermaphroditic, meaning having both sets of gonads (male & female) in one fish.
- **Lateral Line** - organ of microscopic pores
  - that sense low vibrations and water pressure.
- **Nares** - organ to smell; similar to nostrils
- **Nervous System** - organs receiving and interpreting stimuli for nares, eyes, lateral line, muscles, and other tissues.
- **Pectoral Fin** - fins on the sides; used for balance and assist turning.
- **Pelvic Fin** - belly fins on a fish; used for balance and steering.
- **Pyloric Caecae** - “finger-like” organ that aids in digestion, using bile from the liver.
- **Reproductive System** - the organs and tissues involved in reproduction, including gonads, eggs, sperm.
- **Respiratory System** - organs and tissues involved in the oxygen & carbon dioxide gas exchange, including gills, gill rakers, and gill filaments.
- **Scales** - protective cover on a fish; similar to skin.
- **Slime** - slippery covering on scales, protecting fish from bacteria, parasites, etc.
- **Swim bladder** - found only in “ray-finned” fish; a double sac used to assist in buoyancy.
- **Urinary System** - the kidneys remove nitrogen (ammonia) from the blood and regulate water balance in the blood and tissues.
- **Vertebrate** - an organism with a backbone or spine.

**INTERNAL ANATOMY**

**HEART**

This organ pumps blood throughout the body delivering oxygen and digested nutrients to
the cells of various organs. It transports waste products from the cells to the kidneys and liver for elimination. In fish, the circulatory system is a single circuit, with a 2-chambered heart, unlike the typical 4-chambered heart found in land animals like mammals and birds. From the fish’s atrium blood is pumped into the ventricle of the heart. From the ventricle, blood is pumped to the gills where gas exchange takes place in the gill filaments. Carbon dioxide (CO₂) is expelled and oxygen (O₂) is taken in. This re-oxygenated blood then flows on to the rest of the body’s tissues and organs removing carbon dioxide and replacing it with life-giving oxygen. Blood is finally pumped back to the heart’s atrium chamber where the process begins again.

**Liver**
The liver has many digestive and storage functions. One is the production of bile, a solution which emulsifies or breaks down fats in the intestine. The liver also stores fats and carbohydrates, destroys old blood cells, maintains proper blood chemistry, and plays a role in nitrogen waste removal.

**Pyloric Caeca**
This organ with finger-like projections is located near the junction of the stomach and the intestines. It is thought that through the secretion of enzymes it assists in breaking down the food further and absorbs needed nutrients, yet the function of this organ is still not well understood.

**Gonads**
Gonads are the sex organs. Males have paired testes that produce sperm, and females have paired ovaries that produce eggs. In most cases, fertilization of the eggs is performed externally, called spawning.

**Swim Bladder**
Most fish have an organ called the swim bladder. It is a flexible, gas-filled sac located in the dorsal or top portion of the body cavity and helps to control the fish’s buoyancy. Since fish have a density that is heavier than water, they need this swim bladder to not sink when they stop swimming. There are two types of swim bladders, the physostomous and physoclistous.

Fish with a physostomous swim bladder are usually found in shallow water, though some are in deeper water. They will expel bubbles as they swim closer to the surface of the water and then they will swallow air at the surface before diving back down into the water. This air is passed into the guts and then they will force it into the swim bladder.

On the other hand, the physoclistous swim bladder is completely closed off from the swim bladder. These fish are able to control gas exchange or the amount of gas in their swim bladder through the capillaries that are found where the membrane of the swim bladder is very thin.
When a fish is too buoyant, and starts to float upward, gas diffuses out of the swim bladder into the blood. The gas in the blood is removed at the gill filaments and expelled. Conversely, if a fish starts to sink, air enters the swim bladder via a gas gland. Sometimes if a fish is caught and quickly brought to the surface from deep water, their swim bladder may expand so fast that it inflates into their mouth or even burst which usually will kill the fish, unfortunately.

Swim bladders are only found in ray-finned fish. In carp and catfish, the swim bladder is located close to their inner ear and thus giving better auditory ability. Fish with small or no swim bladders, such as darters and flat fish like flounder, sink to the bottom if they stop swimming and have a lowered hearing ability.

**Stomach**

The stomach is often referred to as the gut, and is where food is digested and nutrients absorbed. Fish such as bass are carnivores. Carnivores have fairly short intestines because such food is easy to chemically break down and digest. Fish such as tilapia that are herbivores (eat plants) and require longer intestines because plant matter is usually tough and fibrous and more difficult to break down into usable elements. By examining stomach contents, one can learn a great deal about fish feeding habits. Knowing what a specific fish species eats can also help with bait selection when fishing!

**Kidneys**

Kidneys are organs that filter liquid waste from the blood. The kidney is also extremely important in regulating water and salt concentrations within the fish's body. This allows certain fish species to exist in freshwater or saltwater, and in some cases both as in salmon.

**External Anatomy**

**Fins** All fish have external appendages called fins. Fins allow fish to balance and steer while swimming. Fins are either single along the centerline of the fish like the dorsal fin, anal fin, and tail fin; or paired fins like the pectoral fins and pelvic fins.

The **dorsal fin** helps in steering but its main function is protection, with some species having a
very sharp, spiny dorsal fin. **Pectoral fins** help fish balance and turn. The **pelvic fin** and **anal fin** are located on the belly and help with steering as well as balance. The **tail fin**, also called the caudal fin helps propel a fish forward.

**GILLS**
Located on either side of a fish’s head, gills remove oxygen from the water and diffuse carbon dioxide from the body. The gills are covered by a flexible bony plate called the operculum. Some fish have spines located on the operculum as a defense mechanism to protect them from predators.

**LATERAL LINE**
Running down the length of a fish’s body is the lateral line. It is made up of a series of microscopic holes located just under the scales of the fish. One of the fish's primary sense organs, the lateral line can sense low vibrations in the water, and is capable of determining the direction of their source.

**NARES**
All fish possess a sense of smell. Paired holes called nares, are used for detecting odors in the water, and are located on a fish’s snout. Some fish, such as some shark varieties, catfish, and eels, have a very sharp sense of smell.

**SCALES AND SLIME**
Most fish have scales covering the length of their body. Scales protect fish from injury, much like skin on the human body. On top of these scales is a mucous covering known as the slime layer. Slime protects fish from bacteria and parasites in the water. Anglers should be careful not to remove the slime layer when handling a fish.

**BODY SHAPE**
A fish’s body shape, as well as the shape and size of certain external features, can tell us a lot about that fish. For example, the body shape of a fish can indicate where that fish lives in the water and what type of swimmer it might be. In addition, tail fin shape also signifies a fish’s swimming speed. A sharply forked tail, like that of a shark, implies a fast swimmer, where as a rounded tail means the fish is good at turning.

**MOUTH**
The mouth parts of a fish will vary in size and may or may not contain teeth. The location of the mouth on a fish’s body can also give us a clue as to what may be the fish’s diet. A superior mouth, a mouth pointing upward, means the fish will eat food located above it; where as a fish with an inferior mouth, a mouth pointing downward, will eat food located below it.
**COMPARE & CONTRAST**

Even though humans and fish do not look the same, we share similar organs and body parts.

<table>
<thead>
<tr>
<th>Human</th>
<th>Fish</th>
<th>Human</th>
<th>Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lungs</td>
<td>Gills</td>
<td>Kidneys</td>
<td>Kidneys</td>
</tr>
<tr>
<td>Intestines</td>
<td>Pyloric Caeca</td>
<td>Ears</td>
<td>Lateral Line</td>
</tr>
<tr>
<td>Stomach</td>
<td>Stomach</td>
<td>Skin</td>
<td>Scales &amp; Slime Layer</td>
</tr>
<tr>
<td>Liver</td>
<td>Liver</td>
<td>Nose</td>
<td>Nares</td>
</tr>
<tr>
<td>Ovaries/Teste</td>
<td>Ovaries/Testes</td>
<td>Arms</td>
<td>Pectoral Fins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Legs</td>
<td>Pelvic Fins</td>
</tr>
</tbody>
</table>

**Internal Anatomy**

Clues Across:

1. I am one organ in the digestive system.
2. I am the system that moves blood.
4. We are the organs that help fish reproduce.
6. I am the system that helps make babies.
8. I am the organ that has many digestive and storage functions.
10. I am the system that includes the brain.

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Clues Down:

1. I am the organ that helps fish maintain buoyancy in water.

3. I am the system whose main function is breathing and gas exchange.

5. We are the organs involved in secretion and regulation of water.

7. I am the system that removes wastes.

9. I am the system that breaks down and processes proteins, carbohydrates and fats.

11. I am the organ that helps transport blood.
SLIDES FOR VISUAL INSTRUCTIONS DURING DISSECTION/ORGAN IDENTIFICATION

(Reprinted from NYSDEC Region 1 Freshwater Fisheries I Fish NY Program; https://www.dec.ny.gov/docs/administration_pdf/ifnyfdlp.pdf)

1. Heart
2. Liver
3. Pyloric caecae
4. Adipose, fatty tissue

- Pull the adipose tissue (1) and gut (2) aside to expose the swim bladder (3), gonads (4) and kidneys (5).
- As a general rule, carnivorous fishes have relatively short guts. Herbivorous fishes have much longer guts.
- The gonads and kidneys are paired. One of each can be seen on both sides of the swim bladder.

Remove the right gill cover (operculum) to expose the gills. Bony fish have a single opening behind each operculum.
Push aside other organs to expose the swim bladder; located at the top of the body cavity.

The swim bladder is a flexible-walled, gas-filled sac located in the dorsal portion of body cavity. This organ controls the fish's buoyancy and is used for hearing in some species.

Swim Bladder
If a fish becomes buoyant, and starts to float upwards, gas diffuses out of the swim bladder into the blood. This occurs at a site known as the oval. The gas in the blood is removed from the body at the gills, and expelled into the surrounding water.

Conversely, if a fish starts to sink, air enters the swim bladder at a region called the gas gland. The way the fish does this involves three processes; the acidification of the blood, an increase in the concentration of lactate and hydrogen ions, and the movement of blood through a complex structure called the rete mirabile.

1. Gill filaments
2. Gill rakers
3. Gill arches

Gills: Filaments, Rakers, and Arches

Gills are organs used for breathing. Water enters the mouth, and passes between the gills. Gill filaments absorb the oxygen from the water, and release carbon dioxide. Gill rakers, which aid in feeding processes, are appendages along the front edge of the gill arch. The gill arch provides support for the gills.
ACTIVITY LEARNING OBJECTIVES:
1. Determine the growth rate of fish in the aquaponic system based on both specific growth rate and temperature units.
2. Observe the effects of aeration and other factors on fish respiration.
3. Developing a feeding schedule for the fish tank based on the feed conversion ratio (FCR).

1 gallon = 0.00378 m³, 1 liter = 0.264 gallons, 1 gram = 0.0022 pounds

NGSS PRACTICES:
1. Asking questions
2. Conducting Investigations
3. Analyzing Data
4. Using Mathematics
5. Communicating Information

ESTIMATED TIME:
Discussion: 30 minutes
Activity: 1-2 hours

MATERIALS:
- Balance
- meter stick
- stop watch
- dissolved oxygen meter or test strips
- thermometer

BACKGROUND INFORMATION:
Aquaponic systems must operate near maximum fish production capacity, also called loading density, to be economical. Therefore, fry or fingerlings should be stocked at very high rates at around 30 fish per cubic foot. Feeding rates should be at optimum for rapid fish and plant growth while also making sure not to overfeed.

Loading density, or carrying capacity, is the number or biomass of fish an aquaponic system can support. In a recirculating system, the loading density depends on water flow, volume, exchange rate, temperature, dissolved oxygen, pH, size and species of fish, and the accumulation of metabolic waste. Since dissolved oxygen is affected by temperature, is
directly related to metabolism, its quantity is a function of water volume, and its regeneration is dependent on the water exchange rate, it is often used as the limiting factor when determining loading density. But the general rule is that whatever the limiting factor is, it is used to determine the loading density of fish in the system.

The loading density of a system is usually stated as the pounds of fish per cubic foot of water. Catastrophic fish losses can be caused by overloaded tanks and systems and it is important to remember that the loading density needs to be continuously calculated as the fish grow since the biomass of fish is increasing as they grow. But fish density can often be increased as fish size increases, yet this has to be balanced against the fact that as density increases so may crowding of the fish which can affect their growth rate.

**Growth**

The growth rate of a fish depends on many factors such as diet, care, strain, species, and the water temperature. Knowing the growth rates of fish will help in determining culture tank density, water flow and feeding requirements. Using growth rate as a projection can also help when determining feed orders and tank stocking dates.

One way to predict the growth of fish is to calculate the specific growth rate. Use of the formula is fairly straightforward. You need to measure the weight of a sample of fish on some date, indicated at $t_1$, and then measure the weight of a sample of fish again at a later date, labeled $t_2$. This will help you to determine the growth rate during this time period.

$$ G = \left\{ \frac{\ln W_2 - \ln W_1}{t_2 - t_1} \right\} \times 100 $$

Where:
- $G$ = specific growth rate (% per day)
- $\ln$ = natural log
- $W$ = weight at times 1 ($W_1$) and 2 ($W_2$) in grams
- $t$ = initial ($t_1$) and time passed ($t_2$) in days

There are a variety of ways to predict fish growth and they all depend on what information you have available. Another way to predict the growth of fish in a closed, recirculating system with constant temperature, such as aquaponics, is to base growth on some defined number of temperature units to create a unit of fish growth. In the equation shown, growth is measured as cm per month and assumes that you feed the fish a constant percentage of feed.

$$ G = \frac{T - T_{\text{base}}}{T_{U\text{base}}} $$

$T$ = the constant temperature in your system
$T_{base}$ and $TU_{base}$ are based on historical observations and numerous system records. One precaution, if the temperature in your system is greater than $T_{max}$, then calculate the growth at $T_{max}$, but the excessive temperature will compromise growth and/or feed conversion.

Table 14. Temperature growth units for trout, tilapia and perch, °C (°F)

<table>
<thead>
<tr>
<th></th>
<th>Trout</th>
<th>Tilapia</th>
<th>Perch</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{base}$</td>
<td>0 (32)</td>
<td>18.3 (65)</td>
<td>10 (50)</td>
</tr>
<tr>
<td>$TU_{base}$</td>
<td>6.12 (28)</td>
<td>3.28 (15)</td>
<td>5.47 (25)</td>
</tr>
<tr>
<td>$T_{max}$</td>
<td>22.2 (72)</td>
<td>29.5 (85)</td>
<td>23.9 (75)</td>
</tr>
</tbody>
</table>

For example, if you are raising tilapia with a constant water temperature of 26.7°C or 80°F, then the equation would show 26.7 minus 18.3, divided by 3.28; that results in 2.56 cm of growth per month.

The disadvantage to using this equation is that the temperature units shown in the table have only been published for a few fish species. If you are raising a fish for which the values have not been determined – then either you can’t use this particular method or you would have to figure out the values by “trial and error.”

**AERATION AND RESPIRATION**

The amount of oxygen found in water is called the dissolved oxygen concentration (DO) and is measured in mg/L of water (mg/L = ppm). DO levels are affected by: altitude, types and numbers of plants & algae, water agitation, light penetration, water temperature, and dissolved solids in the water. The concentration of dissolved oxygen in a fish tank is usually the first limiting factor for growth and survival and carrying capacity of the culture system. If dissolved oxygen levels are not maintained at suitable levels, growth will be reduced and feed conversion efficiency will suffer. Chronically low DO levels are stressful, making fish vulnerable to disease.
Desirable to lethal range of dissolved oxygen concentrations for fish.

The concentration at which DO levels begin to stress the fish varies with species, their activity and health, and with concentrations of other water quality variables, namely CO₂, ammonia and nitrite. As a general rule, if effluent DO is equal to or in excess of 5 mg/L, no stress will be placed on the fish.

**Feeds**

The quality of a feed is a function of how well that feed meets the **nutrient requirements** of the fish. Not only must the feed contain the correct proportions of nutrients, but the nutrients must be able to be digested and absorbed in a form that makes them available for providing energy for growth. This is called **bioavailability**; the digestibility of the food is the primary determinant of bioavailability.

Another parameter used to determine the value of food, that provides the necessary energy for growth, is the **food conversion ratio** (FCR) which is also called the utilization energy ratio. The FCR formula is very straight forward but is one all fish culturists know by heart: it is the mass of food consumed by the fish (as dry weight) divided by the increase in mass of the fish (in wet weight) during a period of time for which they consumed the food.

A proper diet should give a good conversion into flesh. With the FCR, the lower the number the more efficient the cultured fish is in converting feed to flesh. It is important
to understand factors affecting the feed conversion ratio since feed costs are some of your most expensive costs of operation.

\[ \text{FCR} = \frac{\text{Mass of food consumed (dry)}}{\text{increase in mass of fish produced (wet)}} \]

Since the FCR formula is fairly easy, let’s look at a slightly complex example. Let’s say you have 1,000 fingerlings, with an average weight of 200 g each. The total live (wet) weight of the fish at the start of the time period would be 200 kg. Then, let’s say the fish are fed 7 g of food/fish/day for 6 months, which is 182 days. And at the time of harvest, the live (wet) weight of each individual fish is 900 g, but there has been 2% mortality in the tank.

First, calculate the final total weight of the fish taking into consideration the mortality that occurred. That would be 1,000 fish minus the 2% lost to mortality. Or 980 fish, each weighing 900 g for a final total live (wet) weight at harvest of 882 kg.

If the fish are fed 7 grams of food per fish each day, and the growth period is 182 days, and you have 1,000 fish to begin with, then you would have fed the fish 1,274 kg of food over the 182 days.

So, you take the total amount of feed fed to the fish, 1,274 kg, and divide by the difference in the weight of fish at the end and the start of the period, 882 kg minus 200 kg = 682 kg, and you get a feed conversion ratio of 1.87.

\[ \text{FCR} = \frac{\text{F}}{\text{W}_f - \text{W}_i} \]

Where:

\( \text{F} \) = weight of food supplied (dry)

\( \text{W}_f \) = live (wet) weight of fish at the end of the time period

\( \text{W}_i \) = live (wet) weight of fish at the start of the time period

**EXERCISE 1: GROWTH**

**DIRECTED INSTRUCTIONS:**

1. Measure the length and weight of 12 juvenile fish from the aquaponic system.
2. Record the date with the data.
3. Wait a specified period of time, (e.g. two weeks), and measure the length and weight of 12 fish from the same aquaponic system again.
4. Calculate the specific growth rate of the fish based on the time period that has passed:

\[ G = \left( \frac{\ln W_2 - \ln W_1}{(t_2 - t_1)} \right) \times 100 \]

Where:
G = specific growth rate (% per day)
ln = natural log
W = weight at times 1 (W₁) and 2 (W₂) in grams
t = initial (t₁) and time passed (t₂) in days

**Activity Guidelines:**
This provides you with information about how much weight the fish are gaining each day based on percent body weight. You could extrapolate the data to predict the growth of the fish in the future and/or review past calculations to better understand why the percent growth is changing. As mentioned earlier, growth of fish is not usually constant and can be influenced by the environment and the life stage of the fish. Younger fish usually grow faster but stressed fish grow slower.

Growth can also be based on temperature units. Measure the water temperature in the fish tank and using that value, calculate the growth (cm per month) of the fish based on temperature growth units:

\[ G = \frac{T - T_{\text{base}}}{TU_{\text{base}}} \]

Using the monthly average water temperature in the fish tank, that you need to record, calculate the monthly temperature units (MTU) for fish in that tank based on the values provided in the temperature unit table earlier in the handout. Now, calculate the MTU’s required to achieve one inch of growth by the fish using the fish length data you previously collected from the juvenile and adult fish and the time period data you recorded.

\[ \text{Monthly growth (inch)} = \frac{\text{MTU for the month}}{\text{MTU required per inch of growth}} \]

Extrapolate your results to show what the expected growth of the fish will be at the end of next month.

**Exercise 2. Aeration and Respiration**
There are a variety of ways that factors affecting respiration can be observed. These experiments can be done in the aquaponic fish tank or the fish can be placed in smaller, clear containers so they can be easily observed. Aerations direct effects on fish respiration can be tested by placing two fish in identical bowls.

1. In one bowl, allow the fish to rest for 15 minutes and then count the number of times the opercular flap opens and closes over 2 minutes.
2. Every time the opercular flap opens, the fish has taken one breadth.
3. For the second fish, that is in an identical bowl, place an airstone in the bowl with the fish and aerate the water gently.
4. After 1-2 minutes, repeat the procedure by counting the number of times the fish opens and closes the opercular flap over 2 minutes. Presumably, the fish with better oxygenated water should breathe less rapidly than the one with less oxygen.
**Activity Guidelines:**
Variations on this experiment can be done by placing the fish in bowls that have different temperatures (less oxygen at warmer temperatures), levels of salinity (less rapid breathing as salinity approaches 3 ppt), and turbidity (more rapid breathing with more solids such as dissolved clay). You could leave the fish in the aquaponic fish tank and have the students measure breathing by observing and counting the opercular flap movement for 2 minutes. Then, feed the fish and once again observe the opercular flap movement for 2 minutes. Feeding should greatly increase oxygen demand by the fish. This could prompt a discussion about fish metabolism and oxygen demand.

**Exercise 3. FCR**
Using the weight data you previously collected about the fish in Exercise 1: Growth, and an estimate of the number of fish in the aquaponic fish tank, calculate the total weight of fish in the tank. Then, based on an optimal feeding rate of 3% body weight per day, calculate the total grams of feed required by the fish in the tank daily.
Finally, calculate the feed conversion ratio (FCR) for the fish based the weight gained by the fish and the amount of food provided to the fish over the same course of time. You’ll need to keep daily records of the amount of feed (grams) provided to the fish each day.

\[
FCR = \frac{F}{(W_f - W_i)}
\]

Where:

\( F \) = weight of food supplied (dry)
\( W_f \) = live (wet) weight of fish at the end of the time period
\( W_i \) = live (wet) weight of fish at the start of the time period
Water quality is the most important production component for raising fish but is often the most neglected. The integration of aquaculture and hydroponics into aquaponics makes water quality a key universal component and the primary variable that travels throughout the whole system.

**Temperature** - Fish are categorized as cold water, cool water, and warm water with each species having an upper & lower limit as well as an optimum range for growth that may change with development.

The temperature for optimum growth of fish is called the standard environmental temperature (SET). It must be recognized that designating a fish as cool water or warm water are broad categories and that variation exists in the optimal temperature for different species that are in the same category. Fish species selection is usually based on anticipated water temperature, however, it is important to remember that the optimum temperature required for egg incubation, growth and development of larval fish and for production of a food-sized fish could be very different.
Table 15. Chemical and physical requirements for specific fish species

<table>
<thead>
<tr>
<th>Category</th>
<th>Optimum temperature (°F)</th>
<th>DO requirement</th>
<th>Ammonia tolerance</th>
<th>Protein requirement</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold water</td>
<td>&lt;60</td>
<td>&gt;5 mg/L</td>
<td>Low</td>
<td>High</td>
<td>Trout, salmon</td>
</tr>
<tr>
<td>Cool water</td>
<td>60-75</td>
<td>&gt;5 mg/L</td>
<td>Low</td>
<td>Moderate</td>
<td>Yellow perch, walleye</td>
</tr>
<tr>
<td>Warm water</td>
<td>&gt;75</td>
<td>&gt;2 mg/L</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Sunfish, bass, minnows</td>
</tr>
<tr>
<td>Tropical</td>
<td>&gt;86</td>
<td>&gt;1 mg/L</td>
<td>High</td>
<td>Low</td>
<td>Cichlid, tetra</td>
</tr>
<tr>
<td>Marine</td>
<td></td>
<td>Higher</td>
<td></td>
<td>Higher</td>
<td></td>
</tr>
<tr>
<td>Freshwater</td>
<td></td>
<td>Lower</td>
<td></td>
<td>Lower</td>
<td></td>
</tr>
</tbody>
</table>

Fish are stressed and disease outbreaks occur after sudden temperature change or when temperatures are chronically near their maximum tolerance. The metabolic rate of ectothermal animals is said to double with each 18°F (10°C) rise in temperature, a relationship called the Q_{10} factor. For example, the recommended feeding rate for 5-6 inch rainbow trout is 1.7 lbs at 50°F but 2.3 lbs at 59°F, a 35% increase over 9°F, not quite reaching at ½ the Q_{10} factor.

Temperature shock, which will stress or cause high mortality of fish, occurs when fish are moved from one environment to another without gradual acclimation to the other temperature. A 0.2°C/minute (12°C/hr) change in temperature can be tolerated by most fish.

It is important to remember that temperature controls the solubility of gases in water, the reaction rate of chemicals, the toxicity of ammonia, and the chemotherapeutic ability of drugs. Water temperature can be measured with a common thermometer or by heat-sensing elements located on DO, pH or other probes.

**pH** is a measure of the hydrogen ions in a solution. It is measured on a logarithmic scale that ranges from a pH=1, which is most acidic, to a pH=14, which is the most basic. A pH=7 is considered neutral. It is important to note the logarithmic nature of pH because this means that each pH value is 10 times more acidic or basic than the next value. For example, pH=4 is ten times more acidic than a pH=5 and 100 times more acidic than a pH=6. It is for that reason that pH is considered an indicator factor. Sudden changes in the pH of an aquaponics system indicate that chemicals in the system are out of balance. That is why pH is the master factor in aquaponics.

The pH of most productive natural waters that are unaffected by pollution is normally in the range of 6.5 to 8.5 at sunrise; typically closer to 7 than 8. Diurnal variation is related to photosynthesis:
1) \( \text{CO}_2 + \text{H}_2\text{O} \overset{\text{Chlorophyll}}{\underset{\text{Sunlight}}{\leftrightarrow}} \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \)

The controlling factor for pH in most aquaculture/aquaponic facilities is the relationship between algal photosynthesis, carbon dioxide (\( \text{CO}_2 \)), and the bicarbonate (\( \text{HCO}_3^- \)) buffering system:

2) \( \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{HCO}_3^- + \text{H}^+ \)

At night, respiration by bacteria, plants, and animals results in oxygen consumption and carbon dioxide production, the reaction in formula (2) goes from left to right, first producing carbonic acid (\( \text{H}_2\text{CO}_3 \)), then bicarbonate \( \text{HCO}_3^- \) and \( \text{H}^+ \) ions; the increase in \( \text{H}^+ \) causes the pH to decrease. During sunlight, respiration continues, but algae use \( \text{CO}_2 \) for photosynthesis, formula (1); the reaction of formula (1) goes from right to left, reducing the abundance of \( \text{H}^+ \) ions and the pH increases. In productive water, especially those with low alkalinity, the daytime pH may reach 10, which can be lethal to young fish. Fish can also die from pH shock, a consequence of a sudden change in pH (> 1.7 pH units) that may occur when moving fish from pond to tank, or tank to pond. There are two methods for measuring pH: a probe/meter and litmus paper.

**NITROGEN COMPONENTS**

Fish excrete the products of protein metabolism, which are the waste products of the food they have eaten, in a form that is called **total ammonia nitrogen** or TAN. TAN is comprised of ammonia (\( \text{NH}_3 \)) and ammonium (\( \text{NH}_4^+ \)). In general, ammonia is much more toxic to fish than ammonium.

In nitrification, ammonia is converted to nitrite which is then converted to nitrate. pH is a controlling factor during this conversion and when you have an alkaline pH, more ammonia (\( \text{NH}_3 \)) will be present, while with an acidic pH, more ammonium (\( \text{NH}_4^+ \)) will be present.

\[
\text{NH}_3 + \text{H}_2\text{O} \leftrightarrow \text{NH}_4 + \text{OH}^-
\]

Low temperature & low pH ⇔ High temperature & high pH

But TAN is not the only nitrogen component in balance. Nitrite is in balance with nitrous acid (\( \text{HNO}_2 \)) and nitrous acid can freely diffuse across the gills of fish, so it is the more toxic form. So, you might think, if you want to prevent ammonia build-up in your aquaponic system, you should keep the pH lower, that is, more acidic. But this favors nitrous acid, which is more toxic to fish than nitrite, and being an acid will continue the decline in pH to more acidic levels. Eventually, the fish will get sick or die from what is called acidosis – or the increased acidity of the blood - which destroys body tissue. This may lead you to try and raise the pH to a more alkaline level, but this favors the buildup of
ammonia and could result in ammonia poisoning of the fish. Of the three types of nitrogen: ammonia, nitrite and nitrate, fish are most sensitive to ammonia. Nitrogen components can be measured using a digital meter or test kits and strips.

**Denitrification is a two-step process:**

1. Ammonia oxidation: $55\text{NH}_4^+ + 76 \text{O}_2 + 109\text{HCO}_3^- \rightarrow \text{C}_5\text{H}_7\text{O}_2\text{N} + 54\text{NO}_2^- + 57\text{H}_2\text{O} + 104\text{H}_2\text{CO}_3$

2. Nitrite oxidation: $400\text{NO}_2^- + \text{NH}_4^+ + 4\text{H}_2\text{CO}_3 + \text{HCO}_3^- + 195 \text{O}_2 \rightarrow \text{C}_5\text{H}_7\text{O}_2\text{N} + 3\text{H}_2\text{O} + 400\text{NO}_3^-$

**Two important points:**

1. Approximately, 4.3 mg O$_2$ are consumed for every mg of ammonia-nitrogen oxidized to nitrate-nitrogen.
2. 8.64 mg of alkalinity in the form of HCO$_3^-$ are consumed per mg of ammonia-nitrogen oxidized. This is a substantial amount of alkalinity and over time will change the characteristics of the water.

**Table 16.** The following table can be used to determine what percentage of the total ammonia-nitrogen is un-ionized (more toxic). To determine if there are toxic levels of un-ionized ammonia in water you must measure three water parameters: total ammonia-Nitrogen, pH, and temperature. Knowing these three things you can calculate the concentration of un-ionized ammonia

<table>
<thead>
<tr>
<th>pH</th>
<th>8°C (46°F)</th>
<th>16°C (61°F)</th>
<th>20°C (68°F)</th>
<th>24°C (75°F)</th>
<th>28°C (82°F)</th>
<th>32°C (90°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>6.8</td>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
<td>0.3</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>7.0</td>
<td>0.1</td>
<td>1.0</td>
<td>0.7</td>
<td>1.0</td>
<td>1.2</td>
<td>1.0</td>
</tr>
<tr>
<td>7.4</td>
<td>0.5</td>
<td>1.0</td>
<td>1.6</td>
<td>1.0</td>
<td>2.7</td>
<td>2.0</td>
</tr>
<tr>
<td>7.6</td>
<td>0.6</td>
<td>1.2</td>
<td>2.1</td>
<td>2.1</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>7.8</td>
<td>1.1</td>
<td>2.0</td>
<td>3.2</td>
<td>3.0</td>
<td>5.3</td>
<td>6.0</td>
</tr>
<tr>
<td>8.0</td>
<td>1.6</td>
<td>2.9</td>
<td>4.3</td>
<td>5.0</td>
<td>8.0</td>
<td>8.4</td>
</tr>
<tr>
<td>8.2</td>
<td>1.9</td>
<td>5.0</td>
<td>6.0</td>
<td>8.0</td>
<td>10.0</td>
<td>13.0</td>
</tr>
<tr>
<td>8.6</td>
<td>3.0</td>
<td>11.0</td>
<td>14.0</td>
<td>17.0</td>
<td>22.0</td>
<td>28.0</td>
</tr>
<tr>
<td>9.0</td>
<td>4.2</td>
<td>23.0</td>
<td>28.0</td>
<td>34.0</td>
<td>41.0</td>
<td>49.0</td>
</tr>
</tbody>
</table>
For example, assume you have used a water quality test kit and found that the water in a fish tank has a total ammonia-N of 10 mg/L. If that water is 75°F with a pH of 8.0, then the following table shows you that 5.0% (or 0.05) of the total ammonia-N is un-ionized.

Now you need to figure out the amount of toxic un-ionized ammonia. To do this, multiply the percent of un-ionized ammonia (from the table we know that is 5%, which as a decimal is 0.05) times the total ammonia (10 mg/L) to get the un-ionized ammonia concentration (0.5 mg/L).

[Here’s the math: Change the 5% to a decimal (0.05) and multiply it by the total ammonia of 10 mg/L for the answer of 0.5 mg/L of un-ionized ammonia-N.]

**ALKALINITY**

The capacity of water to buffer against wide pH swings; sometimes known as the neutralizing capacity of water. It is based on the carbon dioxide / bicarbonate / carbonate buffering system. It is expressed in terms of the equivalent concentration of calcium carbonate (CaCO₃). The pH of the water determines which form dominates. A pH=6.3 is the equilibrium value at which a shift occurs and as pH increases carbonic acid (H₂CO₃) disassociates to form bicarbonate (HCO₃). The equilibrium value of pH=10.4 is when bicarbonate would disassociate to form carbonate (CO₃). Acceptable range for fish and in aquaponics is 40-400 mg/L CaCO₃. Alkalinity can be measured using test kits and strips.

**Dissolved Oxygen** in water is called dissolved oxygen. Water naturally holds less oxygen than air and the amount of dissolved oxygen can be affected by: temperature, agitation, plants, dissolved solids, altitude & salinity. Temperature alone can have a profound effect on the amount of oxygen water can hold; as temperatures increase the solubility of oxygen in water decreases. This is very important in aquaponics since water temperatures are typically maintained at 21-23°C (70-74°F) for plant growth. This means that maximum oxygen solubility in an aquaponics system is 8 – 9 mg/L. Dissolved oxygen should be maintained above 5 mg/L. Though some fish, like tilapia, can survive with lower dissolved oxygen levels and can even come to the surface to swallow air, they do this to survive not grow. Levels below 3 mg/L cause stress in fish and can lead to much greater problems including loss of appetite, disease and death. Oxygen is best measured using a digital meter but can also be measured using an Azide-Winkler chemical test.

**SOLID WASTE** is typically categorized by its size and specific gravity. As the names indicate, settleable solids have a relatively high specific gravity and settle to the bottom of tanks;
suspended solids have a specific gravity that is the same or slightly higher than the water and float in the water; and dissolved solids contribute to the nitrogen components. The primary sources of solids are uneaten fish feed, the solid waste from the fish, bacteria and algae. Settleable and suspended solids can be removed from an aquaponics system using solids filters or clarifiers. Ideally, you should keep solid levels below 80-100 mg/L, though many fish can withstand levels as high as 1,000 mg/L. Persistently high levels of solids can irritate or clog the gills of fish making oxygen absorption difficult. They can also attach to the roots of the plants impairing nutrient and water absorption.

**Turbidity** is sometimes monitored as a proxy for suspended solids. Suspended solids can be measured directly by:

1. Before sampling, prepare glass fiber filters by first soaking them in distilled water, drying them at 103°C, and weighing and recording their weights.
2. Place the dried, weighed glass fiber filter onto a filtering flask – wrinkled side up. Shake the sample bottle first, then pour in the water and turn on the pump. (The amount of water you need to filter may change according to water conditions. Start with 100 mL. Use less volume if the filter gets clogged too quickly and more if the water filters through very fast.) Record the volume of water filtered.
3. Dry the filter at 103 to 105°C, let it cool to room temperature and weigh it. Dry it, cool it, and weigh it again. Continue until the fiber reaches a constant weight. Record the end weight.
4. The increase in weight represents TSS. Calculate TSS by using the equation below.

\[
TSS \text{ (mg/L)} = \frac{([A-B] \times 1000)}{C}
\]

Where
- \( A \) = End weight of the filter
- \( B \) = Initial weight of the filter
- \( C \) = Volume of water filtered

Turbidity is a measurement of the optical property of water – a measure of the amount of light that is scattered and absorbed by particles in the sample. It is a simple measurement that requires the use of either a nephelometer or Jackson turbidimeter to compare a reference solution to the sample. Turbidity measurement does not require any sample preparation, other than shaking the sample bottle well before analysis. The sample is simply poured into a glass tube, placed inside the instrument with a reference solution and the result is read directly from the instrument.
TSS and turbidity samples can be held in the dark on ice or at 4° C. In this condition, TSS Samples can be held for up to 7 days and turbidity samples for up to 2 days.

**Hardness** is the amount of divalent cations in water such as calcium, magnesium, nitrates, sulfates and chlorides. It is often confused with alkalinity, which is derived from carbonate and bicarbonate ions, and directly reflects the buffering capacity of water. It gets even more complicated because some water quality books refer to alkalinity as temporary hardness and both alkalinity and hardness are reported as mg/L calcium carbonate. While there is a connection between water hardness and buffering it needs to be made clear that hardness is a product of mainly calcium and magnesium ions, while buffering (alkalinity) is produced by bicarbonate and carbonate ions. Generally, though there are ample exceptions, hard water is usually well buffered, while soft water is less well buffered. Different species of fish have varied water hardness requirements, but most fish prefer moderate to hard water ranging from 100-300 mg/L CaCO₃. Hardness can be measured using a simple chemical test or strips.

<table>
<thead>
<tr>
<th>Water</th>
<th>Calcium carbonate (mg / liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>0 - 75</td>
</tr>
<tr>
<td>Moderately hard</td>
<td>75 - 150</td>
</tr>
<tr>
<td>Hard</td>
<td>150 - 300</td>
</tr>
<tr>
<td>Very hard</td>
<td>&gt; 300</td>
</tr>
</tbody>
</table>

Water hardness affects fish health because it influences osmoregulation. Being open systems, fish are affected by the makeup of the surrounding water. As a consequence of osmosis, freshwater fish are subject to a continuous influx of water, while marine fish have to live with a continuous outflow of water. Against this continuous movement of water into or out of the body, fish have to maintain a constant internal body fluid concentration – a process called osmoregulation. The greater the difference in concentration between the fish’s body fluids and the surrounding water – the greater the osmotic effect. As hard water is more concentrated than soft, there will be less difference and therefore less water influx and consequently the fish will not have to work so hard at osmoregulation. This is particularly important in cases of bacterial ulceration where water can flood into open tissues.

**Carbon dioxide**

Carbon dioxide is generally not a limiting factor in fish culture. It is present in water as a respiration waste product from fish and can be found in ground water. Free CO₂ should be monitored when fish are raised at high densities and closely monitored if values rise above 20 mg/L. Most fish can acclimate to CO₂ levels as high as 60 mg/L, but fish often avoid zones where CO₂ has risen that high.
The most common methods for lowering CO₂ levels include vigorous aeration and decreasing the feeding level supplied to cultured fish. A CO₂ meter is expensive and since CO₂ is rarely a concerning factor, as long as fish populations are not excessive, few fish farmers have CO₂ meters.

**SALINITY**

Salinity is defined as the total amount of solid material in grams contained in 1 kg of seawater when all the carbonate has been converted to oxide. Salinity can be measured with a hydrometer, which measures the density of the water, or with conductivity meters that measure the electrical charges transmitted through a sample by ions in the water.

Salinity is rarely a concern in freshwater aquaculture (levels are usually less than 0.5 ppt) but may limit the types of fish that can be cultured if groundwater is contained in limestone or NaCl or CaCl rich soils.

---

**Beneficial Bacteria**

**Ammonia oxidizing bacteria (AOB), formerly known as Nitrosomonas**, is a group comprising chemoautotrophic bacteria that oxidize ammonia into nitrite. They have a temperature range of 20 – 30°C and a pH range of 6 – 9. During the conversion, ammonium is combined with oxygen and hydrogen carbonate to produce nitrite, water and carbonic acid.

**Nitrite oxidizing bacteria (NOB), formerly known as Nitrobacter**, is a group comprising chemoautotrophic bacteria that oxidize nitrite into nitrate. They have an optimum pH between 7.3 – 7.5 and can survive temperatures between 0 – 49°C. During conversion, nitrite is combined with ammonium, carbonic acid, hydrogen carbonate and oxygen to produce water and nitrate. The complete conversion process from ammonia to nitrite to nitrate is called **Nitrification**.

---

**Activity 13: Water Quality Testing**

**Activity Objectives:**
1. Conduct water quality testing for each of the parameters listed in the table at each of the locations in the aquaponic system.
2. Based on the results, determine the water quality dynamics in the aquaponic system.
3. Describe the beneficial bacteria (biofilm) along fish tank walls, in the clarifier, the mineralization tank, under the raft, and in the sump tank.
4. Describe the biofilms role in maintaining water quality in the aquaponics system.

**NGSS Practices:**
1. Asking questions
2. Conducting Investigations
3. Analyzing Data
4. Using Mathematics
5. Constructing Explanations
6. Communicating Information
7. Arguing from Evidence

**Estimated Time:**
*Discussion: 30 minutes
Activity: 1 hour per exercise*

**Materials**
- Thermometer
- dissolved oxygen, TAN, nitrite, nitrate, alkalinity, hardness turbidity, pH, and salinity test kits or strips
- hanging drop microscope slides
- cover slips
- Vaseline
- tooth picks
- microscopes

**Directed Instructions:**

**Exercise 1: Water quality testing**
1. Using the appropriate test kit, measure the following water quality parameters in each component of the aquaponics system.

2. Complete the necessary calculations to convert total ammonia nitrogen to unionized ammonia, nitrite-nitrogen to nitrite, nitrate-nitrogen to nitrate, and any additional unit conversions.

3. Present the results along with a discussion comparing the water quality factors among the 5 sampled locations.

4. Discuss differences and similarities in values and what the causes may be.
Table 18. Water quality results from different locations in the aquaponics system.

<table>
<thead>
<tr>
<th></th>
<th>Fish tank</th>
<th>Clarifier</th>
<th>Mineralization</th>
<th>Raft</th>
<th>Sump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissolved oxygen (mg/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total ammonia-nitrogen (mg/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrite-N (mg/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate-N (mg/L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkalinity as mg/L CaCO₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness as mg/L CaCO₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity (NTU) as a proxy for suspended solids</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Exercise 2. Water quality dynamics

1. Using the water quality measurements above, develop a model of water quality dynamics in the aquaponic system.
2. Create a sketch diagram of the aquaponic system, including the 5 parts where you sampled plus the additional components that make up the complete system, and quantify estimates of the nutrient cycle, water quality gains and losses, and the integrated role of the fish, plants and beneficial bacteria.
3. Include in your sketch diagram the major function of each component and what it contributes (or removes) to the system.

Activity Guidelines
This exercise can include discussions on the water cycle, nitrogen cycle, chemistry and geology.

Exercise 3. Biofilm
1. To better understand the ecology of the beneficial bacteria in the aquaponic system make collections of the bacteria from 5 locations within the system: fish tank walls, in the clarifier, the mineralization tank, under the raft, and in the sump tank.

2. To collect bacteria, use a loop to scrape some bacteria (biofilm) from the sampling location. Be sure to use a different loop or rinse the loop, for each sampling location to prevent contamination.

3. Swirl the loop in a 15 mL conical tube containing water to mix and dilute the biofilm. If the biofilm is thin, transfer the collected biofilm directly to the microscope slide.

4. Prepare a cover slip by using a toothpick to place four dots of petroleum jelly on the four corners of the cover slip. Using the loop, transfer a drop of the dilute or concentrated biofilm to the cover slip by gently tapping the loop on in the center of the cover slip.

5. Place a hanging drop slide on the cover slip, centering the depression on the slide over the drop.

6. Invert the slide-cover slip and view the bacteria using the compound microscope slowly increasing magnification to 400x.

7. Draw and describe the cellular morphology: size (small, medium or large), shape, and grouping (individual, pairs, clusters, chains). Look for motility (speed & direction) of the bacteria.

8. Using the wet mount biofilm results, describe differences in the biofilm community from each of the 5 sampled locations. Do the abundance and type of organisms in the biofilm correlate with their role in nutrient conversion and absorption?

**ACCOMMODATIONS & GRADE/LEVEL DIFFERENTIATION:**

Provide students with illustrations and written directions. For more difficult activities heterogeneously group students based on level.
### Table 19. Water Quality for Aquaculture/Aquaponics


<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkalinity (as CaCO$_3$)</td>
<td>50-300</td>
</tr>
<tr>
<td>Aluminum</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Ammonia (NH$_3$-N unionized)</td>
<td>&lt;0.0125 salmonids</td>
</tr>
<tr>
<td>Ammonia (TAN)</td>
<td>&lt;1.0 coolwater fish</td>
</tr>
<tr>
<td>Ammonia (TAN)</td>
<td>&lt;3.0 warmwater fish</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Carbon Dioxide (CO$_2$)</td>
<td>&lt;60 tolerant species (tilapia)</td>
</tr>
<tr>
<td>Carbon Dioxide (CO$_2$)</td>
<td>&lt;20 sensitive species (salmonids)</td>
</tr>
<tr>
<td>Chlorine (Cl)</td>
<td>&lt;0.03</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>&gt;0.006 0.03 depending on Alkalinity</td>
</tr>
<tr>
<td>Hardness Total CaCO$_3$</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Hydrogen cyanide (HCN)</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Hydrogen sulfide (H$_2$S)</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>&lt;0.15</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>&lt;0.15</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Nitrogen (N$_2$)</td>
<td>&lt;110% total gas pressure</td>
</tr>
<tr>
<td>Nitrogen (N$_2$)</td>
<td>&lt;103% nitrogen gas</td>
</tr>
<tr>
<td>Nitrite (NO$_2$)</td>
<td>&lt;1.0, 0.1 in soft water</td>
</tr>
<tr>
<td>Nitrate (NO$_3$)</td>
<td>0-400 or higher</td>
</tr>
<tr>
<td>Dissolved Oxygen (O$_2$)</td>
<td>&gt;5.0 warmwater and coolwater</td>
</tr>
<tr>
<td>Dissolved Oxygen (O$_2$)</td>
<td>&gt;7.0 salmonids</td>
</tr>
<tr>
<td>Ozone (O$_3$)</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>PCBs</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>pH</td>
<td>6.5-8.5</td>
</tr>
<tr>
<td>Phosphorous (P)</td>
<td>0.01-3.0</td>
</tr>
<tr>
<td>Salinity</td>
<td>depends on species</td>
</tr>
<tr>
<td>Silver (Ag)</td>
<td>&lt;0.003</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>&lt;75</td>
</tr>
<tr>
<td>Sulfate (SO$_4$)</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Total Gas Pressure</td>
<td>105% species dependant</td>
</tr>
<tr>
<td>Total Gas Pressure</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Total Dissolved Solids (TDS)</td>
<td>&lt;400 site and species specific</td>
</tr>
<tr>
<td>Total Suspended Solids (TSS)</td>
<td>&lt;80 site and species specific</td>
</tr>
<tr>
<td>Uranium (U)</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Zinc (Z)</td>
<td>&lt;0.005</td>
</tr>
</tbody>
</table>
### TABLE 20. GUIDE TO IDENTIFICATION OF FRESH WATER MICROORGANISMS

Microscopic autotrophic organisms (i.e. algae)  
(Reprinted from https://www.slideshare.net/alealealex/plankton-8525086)

<table>
<thead>
<tr>
<th>Name</th>
<th>Picture</th>
<th>Characteristic</th>
<th>Taxonomy</th>
</tr>
</thead>
</table>
| **Green algae (with flagella, small)** <.05 mm | ![Image](image1.png) | 1. flagella  
2. small  
3. solitary  
4. rapid movement | Phylum Chlorophyceae i.e. *Chlamydomonas* sp. |
| **Green algae (with flagella)** .5-2mm | ![Image](image2.png) | 1. spherical  
2. colonial  
3. with two flagella | Phylum Chlorophyceae i.e. *Volvox* sp. |
| **Green algae (no flagella)** <.5 mm | ![Image](image3.png) | 1. spherical to conical  
2. not attached to surface  
3. no movement | Phylum Chlorophyceae i.e. *Pediastrum* sp. |
| **Filamentous green algae** <.1 mm – cms | ![Image](image4.png) | 1. non branching  
2. chains of cells with chloroplast  
3. no flagella | Phylum Gamophyceae i.e. *Zygnema* sp. *Spirogyra* sp. |
| **Desmids** <.5 mm | ![Image](image5.png) | 1. green  
2. no flagella  
3. mainly solitary, some colonial  
4. various shapes  
5. two semi-cell, mirror image | Phylum Gamophyceae i.e. *Desmidium* sp *Closterium* sp. |
| **Diatoms** <.5 mm | ![Image](image6.png) | 1. one cell  
2. slow gliding motion  
3. solitary or colonial  
4. cell wall (frustules) made of silica | Phylum Bacillariophyceae i.e. Pennales, Centric |
<table>
<thead>
<tr>
<th>Name</th>
<th>Picture</th>
<th>Characteristic</th>
<th>Taxonomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flagellates &lt;.5mm</td>
<td></td>
<td>1. one or more flagella 2. colonial or free living 3. with or without lorica</td>
<td>Zoomastigophora i.e choanoflagellates</td>
</tr>
<tr>
<td>Amoeba .02 –5 mm</td>
<td></td>
<td>1. pseudopodia 2. slow movement 3. engulfs food</td>
<td>Sacrodina Order Amoebina i.e. <em>Amoeba proteus</em></td>
</tr>
<tr>
<td>Shelled Amoeba .1-.4 mm</td>
<td></td>
<td>1. amoeba with a shell, usually sand grains 2. pseudopodia 3. slow movement</td>
<td>Sacrodina Order Testacea i.e <em>Arcella</em> sp.</td>
</tr>
<tr>
<td>Heliozoans .01-1 mm</td>
<td></td>
<td>1. spherical 2. radiating hair like pseudopods 3. no movement</td>
<td>Sacrodina Order Heliozoea</td>
</tr>
<tr>
<td>Ciliates – Peritrich &lt;.25 mm</td>
<td></td>
<td>1. cylindrical or bell shaped bodies 2. undulating cilia 3. some stalked 4. often colonial 5. attached to different substrate</td>
<td>Ciliophora Order Peritrichida i.e. <em>Vorticella</em> sp.</td>
</tr>
<tr>
<td>Ciliates – Suctoria &lt;.7 mm</td>
<td></td>
<td>1. no cilia, sticky tentacles some attached to other organisms (i.e. <em>Suctoria</em>)</td>
<td>Ciliophora Order Eridogenida i.e. <em>Tokophyra</em> sp.</td>
</tr>
</tbody>
</table>
| Ciliates        | Paramecium | 1. mostly free living forms  
|                | .01 – 4mm  | 2. cell of fixed shape  
|                |            | 3. movement by contraction and use of cilia  
|                |            | 4. fixed mouth and anal pore  
| Ciliophora Order Oliogohymenophorea i.e. *Paramecium* sp |
| Ciliates        | Stentor    | 1. large body  
|                | .01 – 4 mm | 2. contractile  
|                |            | 3. cilia on mouth end  
| Ciliophora Order Heterotrichea i.e. *Stentor* sp |
| Ciliates        | Coleps     | 1. barrel-shaped  
|                | .01-4mm    | 2. spinous projection at posterior end  
|                |            | 3. cytosome apical  
| Ciliophora Order Prostomatea i.e. *Coleps* sp |
# GUIDE TO IDENTIFICATION OF FRESH WATER MICROORGANISMS

Other freshwater plankton (Animalia, Monera ,etc.)

<table>
<thead>
<tr>
<th>Name</th>
<th>Picture</th>
<th>Characteristic</th>
<th>Taxonomy</th>
</tr>
</thead>
</table>
| Blue-green algae (cyanobacteria) | ![Picture](image1.png) | 1. blue green color  
2. gliding movement  
3. prokaryote | Kingdom Monera  
i.e. Annabella sp. |
| Euglenoids <.4mm | ![Picture](image2.png) | 1. sometimes green  
2. flagellate  
3. red eye spot | Phylum Euglenida  
i.e. Euglena sp. |
| Dinoflagellates <.4mm | ![Picture](image3.png) | 1. free swimming  
2. tough armor  
3. flagellate  
4. autotrophic, heterotrophic | Phylum Dinoflagellate |
| Rotifers .4mm - 2 cm | ![Picture](image4.png) | 1. corona with cilia  
2. hairy appendages  
3. transparent with loria  
4. free swimming or attached  
5. organs, compressed body | Phylum Rotifer  
Class Bdellooided  
Class Monogononta |
| Hydra 2 cm | ![Picture](image5.png) | 1. green brown or colorless  
2. body and tentacles contract and stretch  
3. primitive organs | Phylum Cnidaria  
i.e. Hydra sp. |
| Flatworms 1-15+ mm | ![Picture](image6.png) | 1. flattened  
2. eye spots  
3. move in gliding motion | Phylum Platyhelminthes  
Class Turbellaria  
i.e. Planaria sp. |
## Guide to Identification of Fresh Water Microorganisms

Other freshwater plankton (Animalia, Monera, etc.)

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>Characteristics</th>
<th>Image</th>
<th>Phylum</th>
</tr>
</thead>
</table>
| Roundworms     | 2-10 mm                                                                      | - moves in rapid “s” form  
- round body  
- bilateral  
- anterior, posterior openings | ![Image](image1.png)            | Phylum Nematodes |
| Oligochaetes   | 1.5 mm - >2 cm                                                               | - segmented  
- worm motion  
- hair bundles (setae) | ![Image](image2.png)            | Phylum Annelida  
Class Oligochaeta |
| Leeches        | > 1 cm                                                                        | - predatory or parasitic  
- terminal suckers  
- hermaphroditic | ![Image](image3.png)            | Phylum Annelida  
Class Hirudinea |
| Gastrotricha   | .1-1.5mm                                                                     | - mainly benthic  
- head bristles  
- eat algae, bacteria, protozoa | ![Image](image4.png)            | Phylum Gastrotricha  
Order Chaetonotida |
| Tardigrades    | Little water bears  
< 1 mm                                                                | - head and 4 trunk segments  
- 4 pair legs  
- eyes  
- herbivores | ![Image](image5.png)            | Phylum Tardigrada |
### Guide to Identification of Fresh Water Microorganisms

**Arthropods – segmented, exoskeletons**

<table>
<thead>
<tr>
<th>Name</th>
<th>Picture</th>
<th>Characteristic</th>
<th>Taxonomy</th>
</tr>
</thead>
</table>
| **Ostracods <2mm**    | ![Ostracods](image) | 1. bean-like shell  
2. filter feeders  
3. bivalve carapace | Class **Crustacea**  
Order **Ostracoda**  
i.e. *Cypris* sp. |
| **Copepods .5-3mm**  | ![Copepods](image) | 1. long antennae  
2. tiny eyespot  
3. holoplankton | Class **Crustacea**  
Order **Copepoda** |
| **Water fleas .3-10mm** | ![Water fleas](image) | 1. antennae  
2. large compound eye  
3. holoplankton | Class **Crustacea**  
Order **Cladocera**  
i.e. *Daphnia* sp |
| **Isopods 5-20mm**   | ![Isopods](image) | 1. flattened  
2. 7 pairs legs  
3. scavengers | Class **Crustacea**  
Order **Isopoda** |
| **Amphipods 5-25mm** | ![Amphipods](image) | 1. curved  
2. compressed body  
3. humped back  
4. scavengers | Class **Crustacea**  
Order **Amphipoda** |
| **Water mites .5-5mm** | ![Water mites](image) | 1. 8 legs  
2. round body  
3. larvae (parasitic)  
4. nymph looks like adult | Class **Arachnida**  
Order **Acarina** |
| **Alderfly nymph 5-25mm** | ![Alderfly nymph](image) | 1. one tail  
2. long filaments along the abdomen  
3. meroplankton | Class **Insecta**  
Order **Megaloptera**  
Family **Sialidae** |
| **Caddisfly larva 3-40mm** | ![Caddisfly larva](image) | 1. cylindrical case for protection  
2. distinct case but different materials | Class **Insecta**  
Order **Trichoptera** |
### Guide to Identification of Fresh Water Microorganisms

**Arthropods – segmented, exoskeletons**

<table>
<thead>
<tr>
<th>Species</th>
<th>Characteristics</th>
<th>Class</th>
<th>Order</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stonefly nymph &lt;15 mm</strong></td>
<td>1. two jointed tails (cerci)</td>
<td>Class Insecta</td>
<td>Order Plecoptera</td>
</tr>
<tr>
<td></td>
<td>2. carnivorous</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. indicates clean water</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mayfly nymph &lt;15mm</strong></td>
<td>1. three jointed tails</td>
<td>Class Insecta</td>
<td>Order Ephemeroptera</td>
</tr>
<tr>
<td></td>
<td>2. leaf-like gills on sides</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Damselfly Nymph &lt;15mm</strong></td>
<td>1. three leaf like tail appendages (gills)</td>
<td>Class Insecta</td>
<td>Order Odonata Zygoptera</td>
</tr>
<tr>
<td></td>
<td>2. extendable jaws</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dragonfly nymph &lt;15mm</strong></td>
<td>1. robust</td>
<td>Class Insecta</td>
<td>Order Odonata Anisoptera</td>
</tr>
<tr>
<td></td>
<td>2. no tail appendages</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. extendable jaws</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Water boatman nymph and adult 10-15mm</strong></td>
<td>1. no jaws</td>
<td>Class Insecta</td>
<td>Order Hemiptera Family Corixidae</td>
</tr>
<tr>
<td></td>
<td>2. tube-like beak</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. nymphs don’t have wings</td>
<td></td>
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</tr>
<tr>
<td><strong>Water beetle &lt;45mm</strong></td>
<td>1. strong jaws</td>
<td>Class Insecta</td>
<td>Order Coleoptera Family Elmidae</td>
</tr>
<tr>
<td></td>
<td>2. tough shield</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. fierce predator</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mosquito larva 1-20 mm</strong></td>
<td>1. long slender body</td>
<td>Class Insecta</td>
<td>Order Diptera</td>
</tr>
<tr>
<td></td>
<td>2. moves in undulating s curves</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX A: ADDITIONAL INFORMATION SOURCES AND PERTINENT WEBSITES


CropKing, Inc, Seville, OH, 800-321-5656 www.cropking.com

Hydro-Aquatic Technologies, Princess Anne, MD, 410-957-2680

AQUAPONICS RELATED WEBSITES
Aquaponics products and information on aquaponics, hydroponics and aquaculture
http://www.aquaponics.com

Cabbage Hill Farm – an excellent site which includes a mini-manual on building an aquaponic greenhouse http://www.cabbagehillfarm.org

University of the Virgin Islands Agricultural Experiment Station - features information on aquaculture and aquaponics research and commercially viable systems
http://rps.uvi.edu/aes/aes_home.html

Fishing For Information – a hypertext guide to Internet resources in aquatic science
http://www.stir.ac.uk/aqua/fishing/default.htm

The GrowRoom – links to hydroponic resources http://www.growroom.com/

Hydroponic Lettuce Production
http://www.cals.cornell.edu/dept/flori/lettuce/cea1.html

Classroom of the Future
http://www.cotf.edu

FISH DISSECTION

“Animals and Sound in the Sea.” Office of Marine Programs. Discovery of Sound in the Sea (DOSITS) 10 October 2008
http://omp.gso.uri.edu/dosits/animals/produce/2f.htm - introduction to the science and uses of sound in ocean research and education. Hear underwater sounds created by marine animals, human activities, and natural phenomena. Video interviews with scientists. For teachers, section with resources and classroom activities.
Florida Fisheries
http://www.iowas.co.uk/fish%20anatomy.html - descriptions of internal and external fish anatomy, organ functions, and details on fish scales.

**BIOFILM IDENTIFICATION RESOURCES:**
An aquaponic system is an excellent tool for experimentation and proving or disproving an hypothesis related to aquaculture, aquaponics or hydroponics. Following are four theories and experiments that can be done to prove each.

**Hypothesis 1:**
Plants need adequate light for growth and development. Insufficient light will produce small plants.

**Experiment 1:**
Set up aquaponic system with artificial lights on 1/2 the plants and no additional lighting on the other 1/2 of the plants. Monitor and document which one best supports plant growth.

**Hypothesis 2:**
A healthy aquaponic system has ample nutrients for leafy crop growth, but fruiting plants might be lacking sufficient quantities of certain elements.

**Experiment 2:**
Plant a leafy crop such as lettuce and a fruiting crop such as tomatoes and monitor to see which one does best in aquaponics.

**Hypothesis 3:**
A pH of 7.0 is the best for an aquaponic system. At a lower pH, nitrification slows down and the water quality will be reduced, stressing the fish. At a higher pH the plants will be stressed.

**Experiment 3:**
Set up three aquaponic systems. Maintain each at a different pH, one at 6.0, one at 7.0 and one at 8.0. Observe and document the ammonia, nitrite and nitrate levels, plant growth and fish health.

**Hypothesis 4:**
Denser fish populations will support more plant growth due to increased fish waste and nutrients in the water. Too dense of a population will not survive.

**Experiment 4:**
Set up two aquaponic systems, stock one with 1” of fish/gallon of water and the other with 1/2” of fish per gallon of water. Observe the difference in plant growth.
Appendix C: Other Related Products from Nelson and Pade, Inc.

- **Aquaponics Journal**
  A quarterly publication covering aquaponics, hydroponics & aquaculture $29/year (electronic subscription), $39/year printed. www.aquaponicsjournal.com

- **Desktop Aquaponics**
  *A booklet that guides you through building and maintaining a desktop aquaponic system.*

- **Introduction to Aquaponics Video (DVD or VHS)**

- **The Encyclopedia of Hydroponic Gardening CD-Rom.**
  *An interactive CD-Rom covering all aspects of hydroponic gardening.*

- **All About Aquaculture CD-Rom**
  *An interactive CD-Rom covering all aspects of fish farming.*

- **Water Gardening CD-Rom**
  *An interactive CD-Rom covering all aspects of water gardening and building garden ponds*

- **Hobby Hydroponics Video**
  *A 30 minute video which demonstrates building and maintaining home hydroponic gardens.*

- **Hydroponics School Curriculum Package**
  *A 10-lesson curriculum using hydroponics to teach principles of botany, plant nutrition, agriculture, horticulture and business. Includes Educator’s Guide, Student’s Manual, CD-Rom, Video and Transparencies*

- **How to Start and Succeed in the Hydroponic Business**
  *A guide to starting and successfully operating a commercial hydroponics business. Includes 100 page manual, sample business plan and a resource listing booklet.*

For more information, call 608-297-8708 or visit www.aquaponics.com
The argument driven approach to the labs included in this curriculum place students in the role of scientist. This essentially means that students will be asking their own questions, formulating hypotheses, and testing those hypotheses based on experiments that they design. For each experiment, students will be asked to defend their argument, just as scientists, based on the evidence they gather.

For each relevant activity, students should complete an argument summary. Instructors could consider asking students or groups of students to present their argument to the class.

Table 21. Argument presentation of experiment.

<table>
<thead>
<tr>
<th>Question:</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Claim:</td>
<td></td>
</tr>
<tr>
<td>Evidence:</td>
<td>Justification of Claim:</td>
</tr>
</tbody>
</table>

**HOW DO YOU CONSTRUCT YOUR CLAIM?**

![Figure 3: The main components of a scientific argument, adapted from NSTA, Argument driven inquiry.](image)

APPENDIX D: ARGUMENT DRIVEN INQUIRY

The argument driven approach to the labs included in this curriculum place students in the role of scientist. This essentially means that students will be asking their own questions, formulating hypotheses, and testing those hypotheses based on experiments that they design. For each experiment, students will be asked to defend their argument, just as scientists, based on the evidence they gather.

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<tbody>
<tr>
<td>Claim:</td>
<td></td>
</tr>
<tr>
<td>Evidence:</td>
<td>Justification of Claim:</td>
</tr>
</tbody>
</table>

**HOW DO YOU CONSTRUCT YOUR CLAIM?**

![Figure 3: The main components of a scientific argument, adapted from NSTA, Argument driven inquiry.](image)
Table 22: Rubric for assessing argument. Each lab that involves writing a hypothesis, designing an experiment and gathering data will be assessed based on the argument you make following the completion of the lab.

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<thead>
<tr>
<th></th>
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<th>0.5</th>
<th>1.5</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CLAIM</strong></td>
<td>Claim is not scientifically correct AND incomplete</td>
<td>Claim is scientifically incorrect OR incomplete</td>
<td>Claim is scientifically correct and complete</td>
<td></td>
</tr>
<tr>
<td><strong>EVIDENCE</strong></td>
<td>Evidence not provided, or only provides inappropriate evidence (evidence that does not support the claim)</td>
<td>Provides appropriate but insufficient evidence to support claim OR also includes some inappropriate evidence</td>
<td>Provides appropriate and sufficient evidence to support claim (e.g. graph or table of data collected during the experiment) AND describes the data</td>
<td></td>
</tr>
<tr>
<td><strong>JUSTIFICATION:</strong></td>
<td>Does not provide reasoning or only provides reasoning that does not link evidence to claim AND The links between the evidence and the claim are based on incorrect ideas AND Does not cite outside research</td>
<td>Some attempt is made to relate evidence to underlying principles, but there are missing pieces OR The evidence is tied to the claim by scientific principles established in the class but there are also extraneous ideas that are incorrect AND Does not cite outside research and/or explain the research</td>
<td>All of the ideas necessary to link the evidence to the claim are included AND The evidence is tied to the claim by scientific principles established in the class AND There are NO extraneous ideas that are incorrect AND Outside research is cited and explained</td>
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<tr>
<td><em>NOTHING TURNED IN / BLANK</em></td>
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APPENDIX E: STANDARD ALIGNMENT BASED ON THE NEXT GENERATION SCIENCE STANDARDS

Figure 4: Adapted from the Next Generation Science Standards. Colors coordinate to each core idea outlined in the aquaponics units.
Table 21: Detailed alignment of Aquaponics activities to Next Generation Core Ideas, Practices, Cross-cutting Disciplines & Wisconsin Agriculture, Food and Natural Resources (AFNR) Standards Alignment

<table>
<thead>
<tr>
<th>Unit</th>
<th>TOPIC</th>
<th>Standard Type</th>
<th>Standard</th>
</tr>
</thead>
</table>
| 1    | INTRODUCTION AND SYSTEM DESIGN | Cross Cutting Concepts | • Scale, Proportion and Quantity  
• Systems & System Models  
• Energy and Matter  
• Stability and Change  
• Structure and Function  
• Interdependence of Science, Engineering & Technology  
• Influence of Engineering, Technology and Science on Society |
|      |       | FROM MOLECULES TO ORGANISMS: STRUCTURES & PRACTICES (LS1) | • Growth and development of organisms (LS1. B)  
• Organization for matter and energy flow in organisms (LS1.C) |
|      |       | ECOSYSTEMS: INTERACTIONS, ENERGY, AND DYNAMICS (LS2) | • Interdependent relationships in ecosystems (LS2.A)  
• Cycles of matter and energy transfer in ecosystems (LS2.B)  
• Ecosystem dynamics, functioning, and resilience (LS2.C) |
|      |       | MATTER AND ITS INTERACTIONS (PS1) | • Structure and property of matter |
|      |       | ENERGY (PS3) | • Conversion of energy and energy transfer (PS3.B)  
• Energy in chemical processes and everyday life (PS3.C) |
|      |       | EARTH AND HUMAN ACTIVITY (ESS3) | • Natural Resources (ESS3.A)  
• Human Impacts on Earth Systems (ESS3.C) |
<p>|      |       | ENGINEERING DESIGN (ETS1) | • Optimizing the design solution |</p>
<table>
<thead>
<tr>
<th></th>
<th><strong>LINKS AMONG ENGINEERING, TECHNOLOGY, SCIENCE, AND SOCIETY (ETS2)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Interdependence of Science, Engineering, and Technology</td>
</tr>
<tr>
<td></td>
<td>• Influence of Engineering, Technology, and Science of Society and the Natural World</td>
</tr>
<tr>
<td>Practices</td>
<td>• Asking questions</td>
</tr>
<tr>
<td></td>
<td>• Conducting Investigations</td>
</tr>
<tr>
<td></td>
<td>• Analyzing Data</td>
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<tr>
<td></td>
<td>• Using Mathematics</td>
</tr>
<tr>
<td></td>
<td>• Constructing Explanations</td>
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<tr>
<td></td>
<td>• Communicating Information</td>
</tr>
<tr>
<td></td>
<td>• Arguing from Evidence</td>
</tr>
<tr>
<td>AFNR</td>
<td><strong>AS1</strong>: Examine components, historical development, global implication and future trends of animal systems industry</td>
</tr>
<tr>
<td></td>
<td><strong>AS7</strong>: Select animal facilities and equipment that provide for the safe and efficient production, housing and handling of animals</td>
</tr>
<tr>
<td></td>
<td><strong>BT1</strong>: Recognize the historical, social cultural and potential application of biotechnology</td>
</tr>
<tr>
<td></td>
<td><strong>FPP1</strong>: Examine components of the food industry and historical development of food products and processing</td>
</tr>
<tr>
<td></td>
<td><strong>ESS2</strong>: Apply scientific principles to environmental service systems</td>
</tr>
<tr>
<td></td>
<td><strong>ESS3</strong>: Operate environmental service systems to manage a facility environmental service system</td>
</tr>
<tr>
<td></td>
<td><strong>2 ESTABLISHING AND MAINTAINING THE CROSS CUTTING CONCEPTS</strong></td>
</tr>
<tr>
<td></td>
<td>• Cause and Effect</td>
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<td></td>
<td>• Scale, Proportion and Quantity</td>
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<td></td>
<td>• Systems &amp; System Models</td>
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<td></td>
<td>• Energy and Matter</td>
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<tr>
<td></td>
<td>• Stability and Change</td>
</tr>
<tr>
<td>Core Ideas</td>
<td>Practices</td>
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<tr>
<td>---------------------------------------------------------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>- Structure and Function</td>
<td>- Asking questions</td>
</tr>
<tr>
<td>- Interdependence of Science, Engineering &amp; Technology</td>
<td>- Conducting Investigations</td>
</tr>
<tr>
<td>- Influence of Engineering, Technology and Science on Society</td>
<td>- Analyzing Data</td>
</tr>
<tr>
<td>- From Molecules to Organisms: Structures &amp; Practices (LS1)</td>
<td>- Using Mathematics</td>
</tr>
<tr>
<td>- Growth and development of organisms (LS1. B)</td>
<td></td>
</tr>
<tr>
<td>- Organization for matter and energy flow in organisms (LS1.C)</td>
<td></td>
</tr>
<tr>
<td>- Ecosystems: Interactions, Energy, and Dynamics (LS2)</td>
<td></td>
</tr>
<tr>
<td>- Interdependent relationships in ecosystems (LS2.A)</td>
<td></td>
</tr>
<tr>
<td>- Cycles of matter and energy transfer in ecosystems (LS2.B)</td>
<td></td>
</tr>
<tr>
<td>- Ecosystem dynamics, functioning, and resilience (LS2.C)</td>
<td></td>
</tr>
<tr>
<td>- Matter and Its Interactions (PS1)</td>
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<tr>
<td>- Structure and property of matter</td>
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<tr>
<td>- Energy (PS3)</td>
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<tr>
<td>- Conversion of energy and energy transfer (PS3.B)</td>
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<tr>
<td>- Energy in chemical processes and everyday life (PS3.C)</td>
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<tr>
<td>- Engineering Design (ETS1)</td>
<td></td>
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<tr>
<td>- Optimizing the design solution</td>
<td></td>
</tr>
<tr>
<td>- Links among Engineering, Technology, Science, and Society (ETS2)</td>
<td></td>
</tr>
<tr>
<td>- Interdependence of Science, Engineering, and Technology</td>
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</tr>
</tbody>
</table>
| 3 | SEED GERMINATION AND PLANTING | AS5: Evaluate and select animals based on scientific principles of animal production  
AS6: Prepare and implement animal handling procedures for the safety of animals, producers and consumers of animal products  
AS7: Select animal facilities and equipment that provide for the safe and efficient production, housing and handling of animals  
BT1: Recognize the historical, social cultural and potential application of biotechnology  
FPP1: Examine components of the food industry and historical development of food products and processing  
ESS2: Apply scientific principles to environmental service systems.  
ESS3: Operate environmental service systems to manage a facility environmental service system |  
| | Cross Cutting Concepts | • Cause and Effect  
• Energy and Matter  
• Stability and Change  
• Structure and Function |  
| | Core Ideas | FROM MOLECULES TO ORGANISMS: STRUCTURE AND PROCESSES (LS1)  
• Structure and Function (LS1.A)  
• Growth and Development (LS1.B)  
• Organization for Matter and Energy flow in Organisms (LS1.C)  
ECOSYSTEMS: INTERACTIONS, ENERGY, AND DYNAMICS (LS2)  
• Interdependent Relationships in Ecosystems (LS2.A)  
• Cycles of Matter and Energy transfer in Ecosystems (LS2.B)  
MATTER AND ITS INTERACTIONS (PS1)  
• Chemical Reactions (PS1.B)  
ENERGY (PS3) |
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</table>
|   | • Conservation of Energy and Energy Transfer (PS3.B)  
  • Energy in Chemical Processes (PS3.D)  
  **WAVES (PS4)**  
  • Wave Properties (PS4.A)  
  • Electromagnetic radiation (PS4.B)  
  **LINKS AMONG ENGINEERING, TECHNOLOGY, SCIENCE, AND SOCIETY (ETS2)** |   |
| Practices |   | • Asking questions  
  • Conducting Investigations  
  • Analyzing Data  
  • Using Mathematics  
  • Constructing Explanations  
  • Communicating Information  
  • Arguing from Evidence |   |
|   |   |   |
| AFNR | **ESS4**: Examine the relationships between energy sources and environmental service system with a basic understanding of the tools, equipment, machinery and technology to accomplish tasks in environmental service system  
  **PS1**: Apply knowledge of plant classification, anatomy and physiology to the production and management of plants  
  **PS2**: Prepare and implement a plant management plan that addresses the influence of environmental factors, nutrients and soil on plant growth  
  **PS3**: Propagate, culture and harvest plants  
  **PS5**: Recognize different systems in which plants grow |   |
|   |   |   |
| 4 |   | **Cross Cutting Concepts**  
  • Cause and Effect  
  • Scale, Proportion and Quantity |   |
<table>
<thead>
<tr>
<th>Core Ideas</th>
<th>Practices</th>
</tr>
</thead>
</table>
| **FROM MOLECULES TO ORGANISMS: STRUCTURE AND PROCESSES (LS1)**  
• Structure and Function (LS1.A)  
• Growth and Development (LS1.B)  
• Organization for Matter and Energy flow in Organisms (LS1.C)  
**ECOSYSTEMS: INTERACTIONS, ENERGY, AND DYNAMICS (LS2)**  
• Interdependent Relationships in Ecosystems (LS2.A)  
• Cycles of Matter and Energy transfer in Ecosystems (LS2.B)  
• Ecosystem Dynamics, Function and Resilience (LS2.C)  
**HEREDITY INHERITANCE AND VARIATION OF TRAITS (LS3)**  
• Variations of Traits (LS3.B)  
**BIOLOGICAL EVOLUTION: UNITY AND DIVERSITY (LS4)**  
• Adaptation (LS4.C)  
**EARTH AND HUMAN ACTIVITY (ESS3)**  
• Natural Resources (ESS3.A)  
**ENGINEERING DESIGN (ETS1)**  
• Defining and Delimiting engineering problems (ETS1.A)  
• Developing Possible Solutions (ETS1.B)  
• Optimizing the Design Solution (ETS1.C)  
**MATTER AND ITS INTERACTIONS (PS1)**  
• Structure and Properties of Matter (PS1.A)  
• Chemical Reactions (PS1.B)  
**ENERGY (PS3)**  
• Conservation of Energy and Energy Transfer (PS3.B)  
• Energy in Chemical Processes (PS3.D)  
**LINKS AMONG ENGINEERING, TECHNOLOGY, SCIENCE, AND SOCIETY (ETS2)**  
• Asking questions  
• Conducting Investigations  
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• Using Mathematics |
| AFNR | Constructing Explanations  
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<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td></td>
<td>ESS4: Examine the relationships between energy sources and environmental service system with a basic understanding of the tools, equipment, machinery and technology to accomplish tasks in environmental service system</td>
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<tr>
<th>5</th>
<th>PLANT NUTRIENT REQUIREMENTS</th>
<th>Cross Cutting Concepts</th>
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<td></td>
<td></td>
<td>•Cause and Effect</td>
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<td>•Scale, Proportion and Quantity</td>
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<td>•Stability and Change</td>
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<td>•Structure and Function</td>
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5 PLANT NUTRIENT REQUIREMENTS
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<td>• Interdependent Relationships in Ecosystems (LS2.A)</td>
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<td>• Cycles of Matter and Energy transfer in Ecosystems (LS2.B)</td>
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<tr>
<td><strong>EARTH’S SYSTEMS (ESS1)</strong></td>
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<tr>
<td>• Weather and Climate (ESS2.D)</td>
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<tr>
<td><strong>EARTH AND HUMAN ACTIVITY (ESS3)</strong></td>
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</tr>
<tr>
<td>• Natural Resources (ESS3.A)</td>
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<tr>
<td>• Human Impacts on Earth Systems (ESS3.C)</td>
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<tr>
<td><strong>ENGINEERING DESIGN (ETS1)</strong></td>
<td></td>
</tr>
<tr>
<td>• Optimizing the Design Solution (ETS1.C)</td>
<td></td>
</tr>
<tr>
<td><strong>LINKS AMONG ENGINEERING, TECHNOLOGY, SCIENCE, AND SOCIETY (ETS2)</strong></td>
<td></td>
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</tbody>
</table>
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|---|---|
| Cross Cutting Concepts | • Cause and Effect  
• Scale, Proportion and Quantity  
• Systems & System Models  
• Energy and Matter  
• Stability and Change  
• Structure and Function |
| **FROM MOLECULES TO ORGANISMS: STRUCTURE AND PROCESSES (LS1)** |  
• Structure and Function (LS1.A)  
• Organization for Matter and Energy flow in Organisms (LS1.C)  
**ECOSYSTEMS: INTERACTIONS, ENERGY, AND DYNAMICS (LS2)**  
• Cycles of Matter and Energy transfer in Ecosystems (LS2.B)  
• Ecosystem Dynamics, Function and Resilience (LS2.C)  
**EARTH’S SYSTEMS (ESS1)**  
• Weather and Climate (ESS2.D)  
**EARTH AND HUMAN ACTIVITY (ESS3)**  
• Natural Resources (ESS3.A)  
• Human Impacts on Earth Systems (ESS3.C)  
**MATTER AND ITS INTERACTIONS (PS1)** |
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| AFNR | **ESS4**: Examine the relationships between energy sources and environmental service system with a basic understanding of the tools, equipment, machinery and technology to accomplish tasks in environmental service system  
**PS1**: Apply knowledge of plant classification, anatomy and physiology to the production and management of plants  
**PS2**: Prepare and implement a plant management plan that addresses the influence of environmental factors, nutrients and soil on plant growth  
**PS3**: Propagate, culture and harvest plants  
**PS5**: Recognize different systems in which plants grow |
| Cross Cutting Concepts |  
**Scale, Proportion and Quantity**  
**Systems & System Models**  
**Energy and Matter**  
**Structure and Function**  
**Patterns** |
| FISH ANATOMY & PHYSIOLOGY | **FROM MOLECULES TO ORGANISMS: STRUCTURE AND PROCESSES (LS1)**  
- Structure and Function (LS1.A)  
- Growth and Development (LS1.B)  
**HEREDITY INHERITANCE AND VARIATION OF TRAITS (LS3)**  
- Inheritance of Traits (LS3.A)  
- Variations of Traits (LS3.B)  
**BIOLOGICAL EVOLUTION: UNITY AND DIVERSITY (LS4)**  
- Evidence of Common Ancestry and Diversity (LS4.A)  
- Adaptation (LS4.C)  
- Biodiversity and Humans (LS4.D)  
- Developing Possible Solutions (ETS1.B) |
| Practices | **Conducting Investigations** |
| AFNR | AS2: Classify, evaluate, select and manage animals based on anatomical and physiological characteristics  
AS3: Provide for the proper health care of animals  
AS4: Apply principles of animal nutrition to ensure the proper growth, development, reproduction and economic production of animals  
AS5: Evaluate and select animals based on scientific principles of animal production  
AS6: Prepare and implement animal handling procedures for the safety of animals, producers and consumers of animal products  
AS7: Select animal facilities and equipment that provide for the safe and efficient production, housing and handling of animals  
AS8: Analyze environmental factors associated with animal production  
BT2: Demonstrate laboratory skills as applied to biotechnology  
FPP1: Examine components of the food industry and historical development of food products and processing  
FPP2: Apply safety principles; recommend equipment and facility management techniques to food products and processing industry  
FPP3: Apply principles of science to the food products and processing industry  
FPP4: Select and process food products for storage, distribution and consumption |  
| FISH NUTRITION AND HEALTH | Cross Cutting Concepts  
• Cause and Effect  
• Scale, Proportion and Quantity  
• Systems & System Models  
• Energy and Matter |
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**MATTER AND ITS INTERACTIONS (PS1)**  
- Structure and Properties of Matter (PS1.A)  
- Chemical Reactions (PS1.B)  
**ENERGY (PS3)**  
- Conservation of Energy and Energy Transfer (PS3.B)  
- Energy in Chemical Processes (PS3.D)  
**ENGINEERING DESIGN (ETS1)**  
- Defining and Delimiting engineering problems (ETS1.A)  
- Developing Possible Solutions (ETS1.B)  
- Optimizing the Design Solution (ETS1.C)  
**LINKS AMONG ENGINEERING, TECHNOLOGY, SCIENCE, AND SOCIETY (ETS2)**  
- Asking questions  
- Conducting Investigations  
- Analyzing Data  
- Using Mathematics |
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| • Stability and Change  
• Interdependence of Science, Engineering & Technology  
• Influence of Engineering, Technology and Science on Society |
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| Practices | AS4: Apply principles of animal nutrition to ensure the proper growth, development, reproduction and economic production of animals  
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 ESS1: Use analytical procedures to plan and evaluate environmental service systems while assessing the impact of policies and regulations on environmental service systems  
 ESS2: Apply scientific principles to environmental service systems  
 ESS3: Operate environmental service systems to manage a facility environment  
 ESS4: Examine the relationships between energy sources and environmental service system with a basic understanding of the tools, equipment, machinery and technology to accomplish tasks in environmental service system |
|---|---|
| Cross Cutting Concepts | 12 THE ENGINEERING, TECHNOLOGY AND MATH OF AQUAPONICS *  
 •Cause and Effect  
 •Scale, Proportion and Quantity  
 •Systems & System Models  
 •Energy and Matter  
 •Interdependence of Science, Engineering & Technology  
 •Influence of Engineering, Technology and Science on Society  
 Core Ideas | ENGINEERING DESIGN (ETS1)  
 •Defining and Delimiting engineering problems (ETS1.A) |
| Practices | 
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| • Asking questions  
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• Using Mathematics  
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| AFNR | 
| FPP2: Apply safety principles; recommend equipment and facility management techniques to food products and processing industry  
FPP3: Apply principles of science to the food products and processing industry  
ESS2: Apply scientific principles to environmental service systems  
ESS3: Operate environmental service systems to manage a facility environment |
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