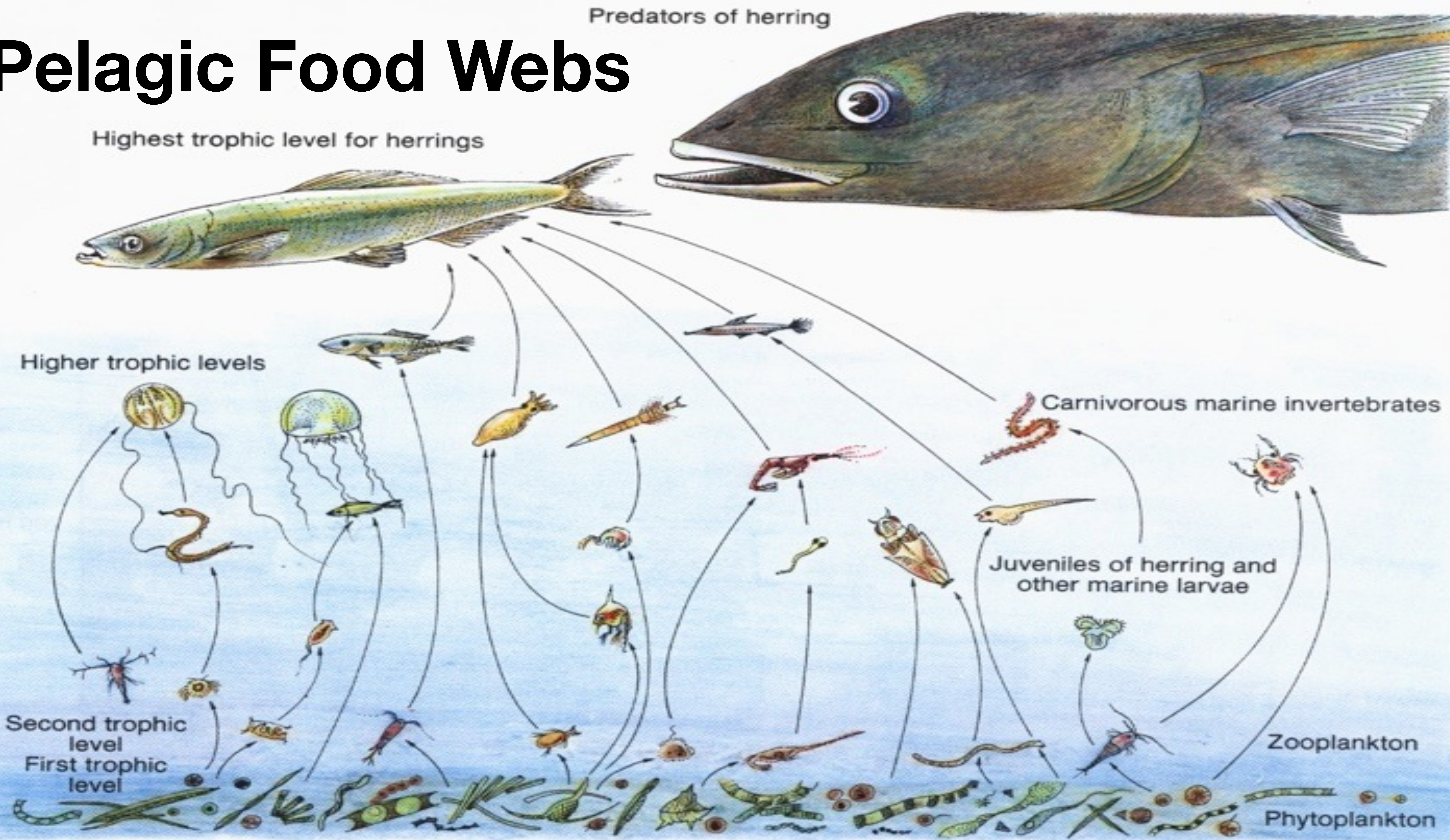
# Pelagic Food Webs



## We Will Have About 25 Special Guests Joining the Class Today

Mr. Reiff's 3rd grade class will attend the last 10 minutes of class to hear about how I became an oceanographer…

This is also suppose to be an important message to you!

# Outline

1. Some Definitions
2. Zooplankton Groups
3. Size-Structured Food Webs >>> Food Chains
4. Trophic Transfer Efficiency
   - ✦ exploitation efficiency
   - ✦ gross production efficiency
5. Consequences of food chain length on harvestable fish production

# Section I

1. Some Definitions
2. Zooplankton Groups
3. Size-Structured Food Webs >>> Food Chains

# Definitions

**Pelagic**: The Water Column Environment

**Benthic**: The Seafloor Environment

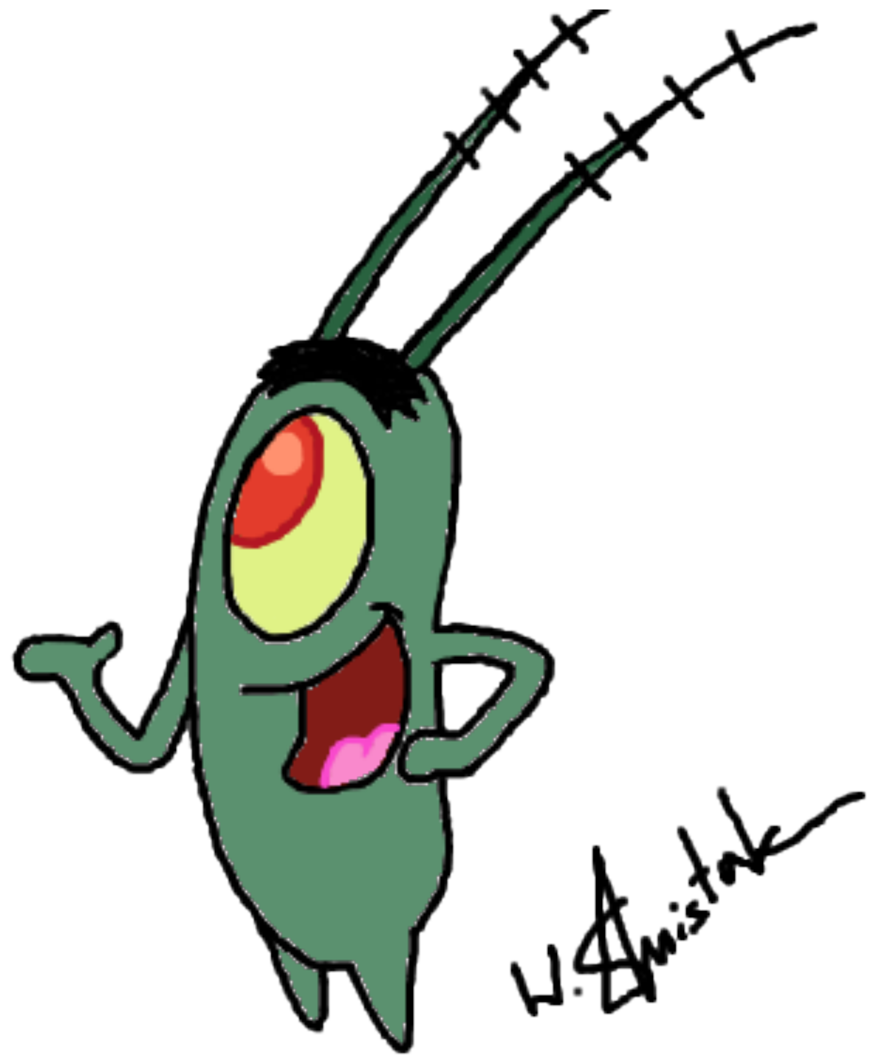
- also includes coral reefs and rocky intertidal

**Plankton**: Unable to swim horizontally against ocean currents, but some may be able to move vertically in the water column

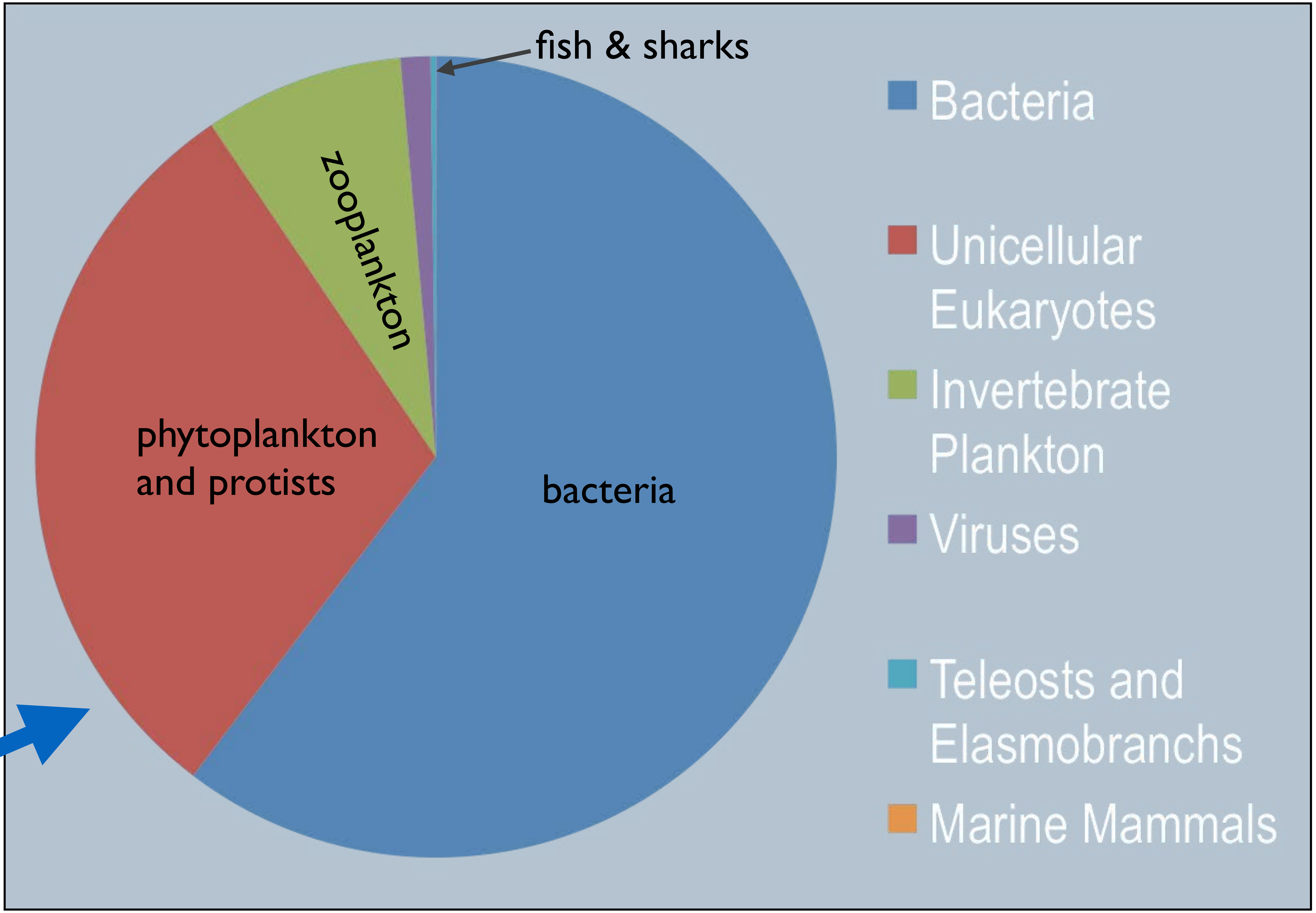
- phytoplankton
- zooplankton

**Nekton**: Able to swim against ocean currents

- e.g., fish, squid, sea turtles, dolphins, whales



## Why all the Focus on Phytoplankton and Zooplankton and not Fish, Sharks and Whales?




Proportion of Living Biomass in the Global Ocean

# Major Zooplankton Groups in Pelagic Food Webs

## Holoplankton

Planktonic organisms that live their **entire life** in fluid suspension.

**Examples:**

- **Copepods**
- Some Shrimp
- Arrow Worms
- Some Jelly Fish

## Meroplankton

Planktonic organisms that spend only **part of their life** in fluid suspension

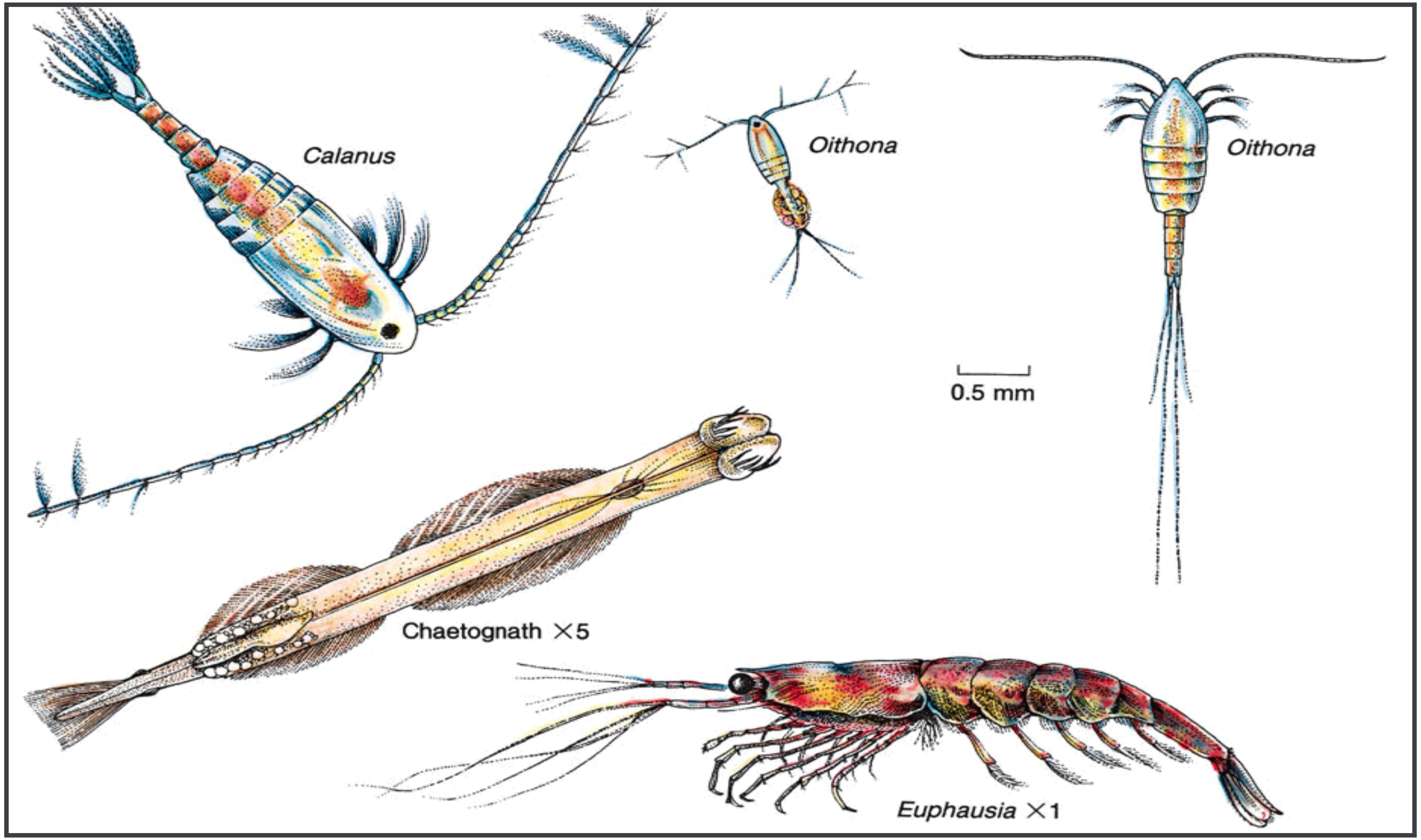
**Examples:**

- Crabs
- Barnacles
- Oysters
- Fish Larvae

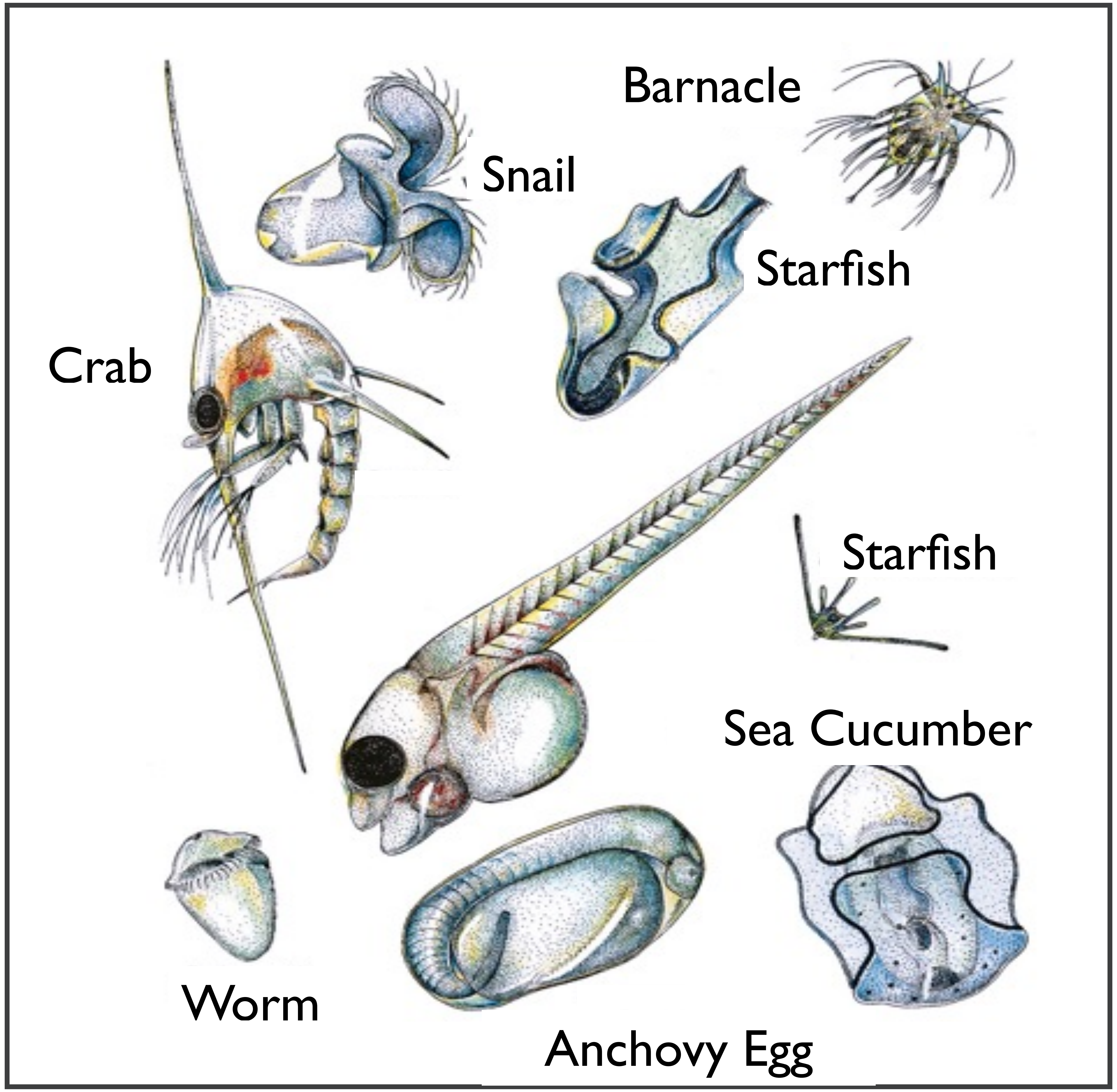
# The Zooplankton Zoo!


http://www.thisiscolossal.com/2014/04/a-single-drop-of-seawater-magnified-25-times/

# Zooplankton (Holoplankton)



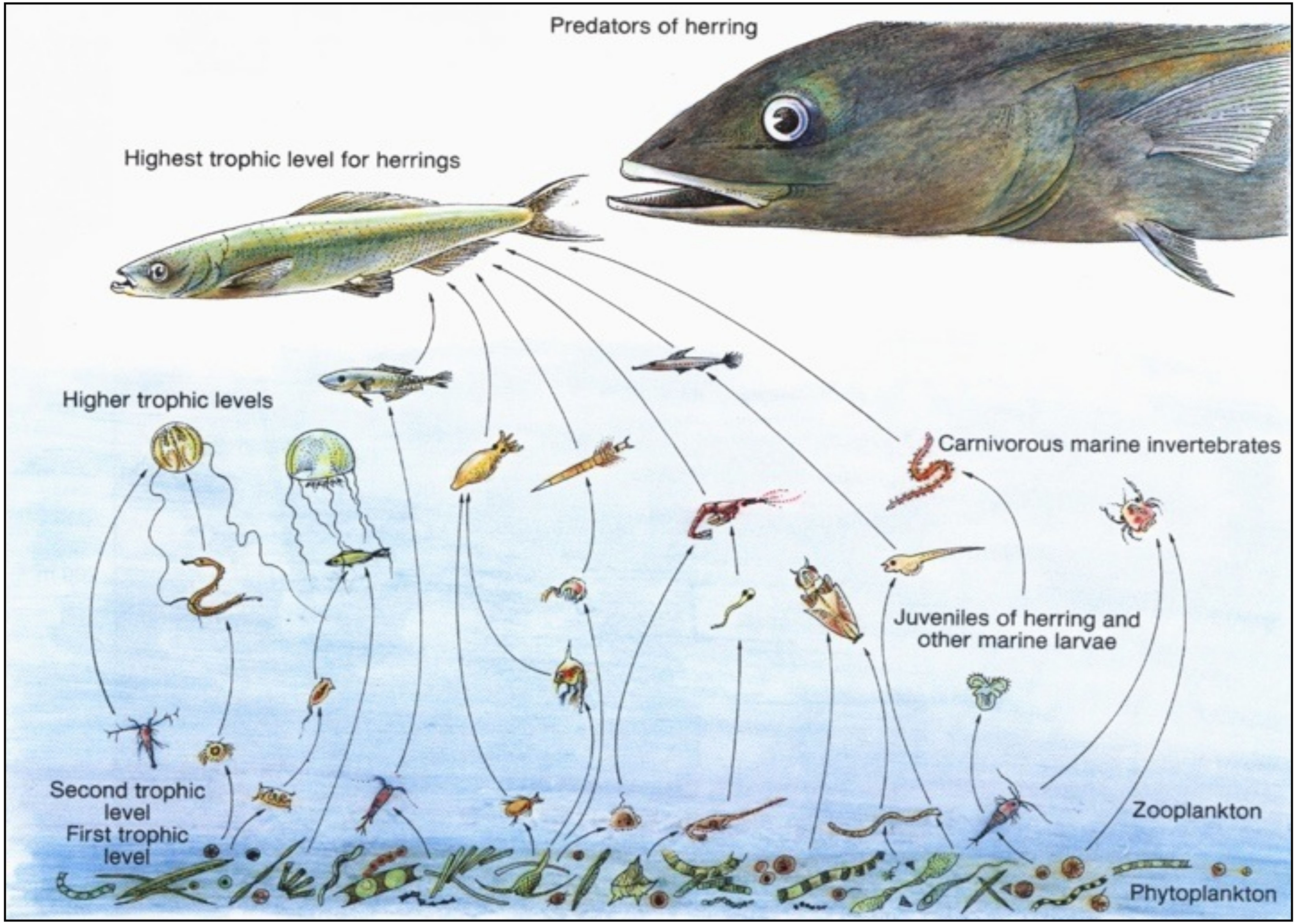
# Zooplankton
(Meroplankton)



# Pelagic Food Chains

## A Simplified View of Pelagic Food Webs

# Pelagic Food Web



# Simplifying Complex Food Webs…

- Complex food webs are simplified by grouping/classifying all species into a small number of broad categories.

- An individual organism's membership in a given category is often determined by…

1. What are the **main food sources** of the organism?

2. Who are the **main predators** of the organism?

# Classifying Organisms into Broad Categories Based on Feeding Mode

## Broadest Possible Grouping…

**Autotrophs:** Group of organisms whose **energy/carbon** for growth comes from **non-organic sources.** For example, phytoplankton are autotrophs because they use sunlight and $CO_2$ for their energy/carbon needs.

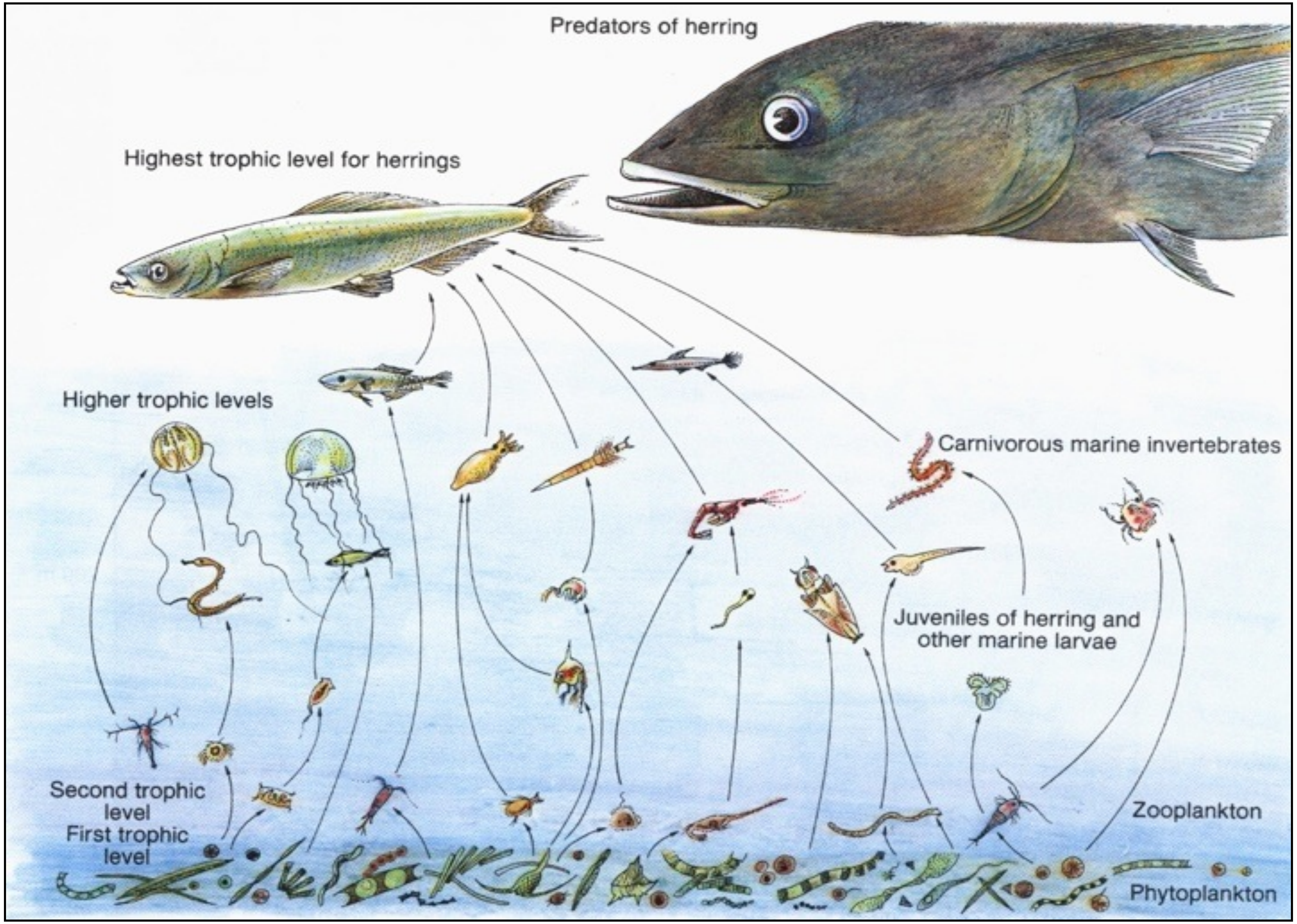
**Heterotrophs:** Group of organisms whose **energy/carbon** for growth comes from **previously formed organic carbon material.** For example, herbivorous zooplankton are heterotrophs because they consume phytoplankton for their energy/carbon needs. Carnivores would also be heterotrophs

## An Extended Grouping Method…

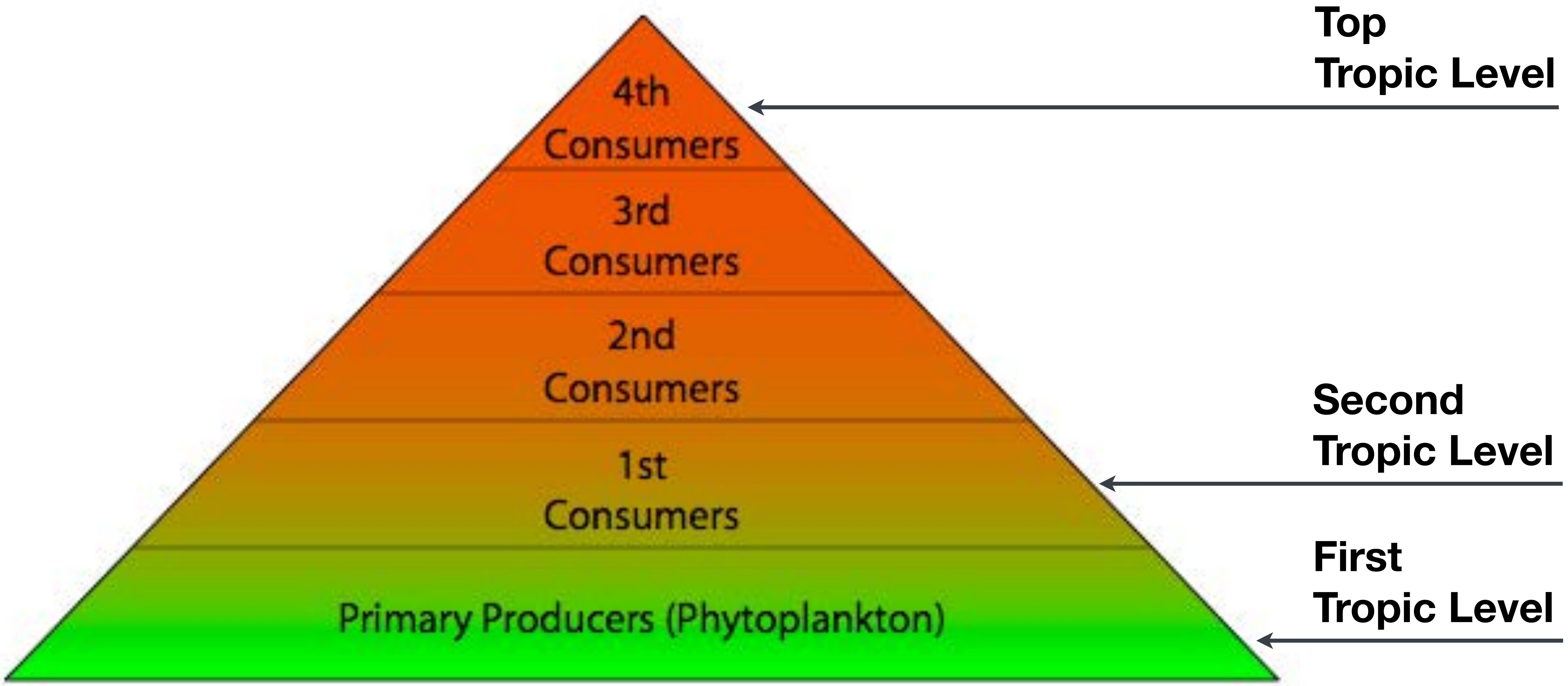
**Trophic Level:** Nutritional feeding levels within a food chain or food web

e.g., primary producer (i.e., autotroph), primary consumer (herbivore), secondary consumer (first carnivore), tertiary consumer (second carnivore), etc…

# Pelagic Food Web



# Simplified Pelagic Food Chain Conceptualization



# Questions to be Addressed About Pelagic Food Chains…

1. How is a particular species assigned to a given trophic level?
2. What determines the efficiency of transfer of carbon or energy from one trophic level to the next?
3. What are the consequences of trophic transfer efficiency on setting the upper limit of harvestable fish production?
4. What regions of the ocean are responsible for the greatest levels of harvestable fish and why?

# How do we Assign an Organism to a Particular Trophic Level?

# The First Question to Ask...

*Is the Organism* ***Autotrophic*** *or* ***Heterotrophic****?*

The answer to this question is pretty straightforward because it amounts to asking…

**Does the Organism Contain Chlorophyll?**

- **yes**, then it is an autotroph
- **no**, then it is a heterotroph

# Then the Next Question to Ask...

*Is the heterotrophic organism a **primary consumer** or a **secondary consumer** or a **tertiary consumer** etc…?*

**This question has the potential of being difficult to answer because all heterotrophic organisms share the same trait of not having chlorophyll.  To get to the answer, the following logic is use:**

1. Life in fluid suspension does not allow animals the opportunity to sit around and nibble on their prey over an extended period of time.
2. Animals in fluid suspension, in general, must consume their prey whole.
3. The need to consume whole prey puts strong constraints on the size of prey that can be consumed by an organism
4. **Optimal prey size is often set by the consumer's mouth size and, *as a rule-of-thumb*, prey size is often about 1/10 the consumer's size.**

# As a general rule, the preferred prey size is approximately 1/10 of consumer size

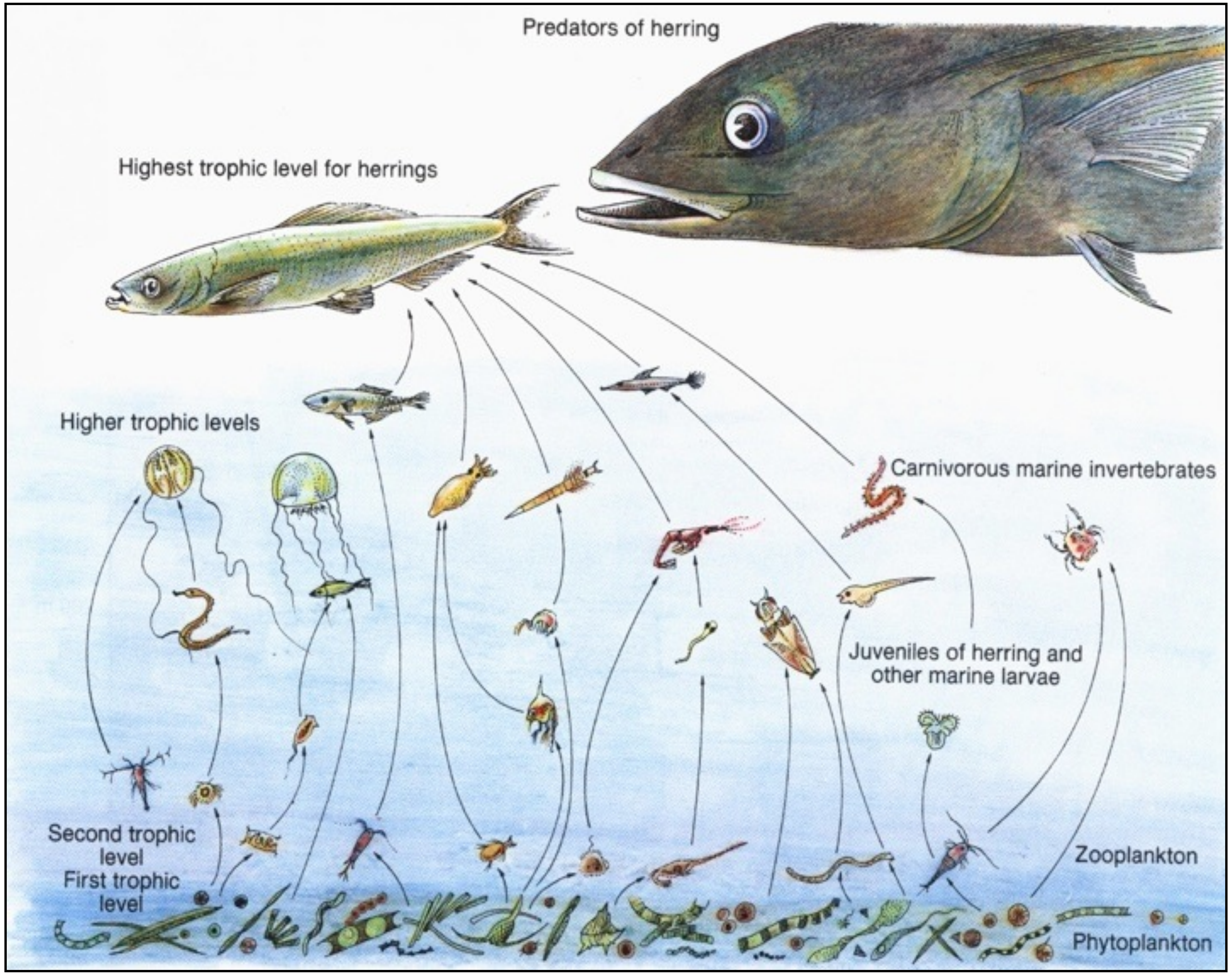
Size determines almost everything about an organism's position/role in the community of pelagic organisms

**except for the possibility of containing or not containing chlorophyll*

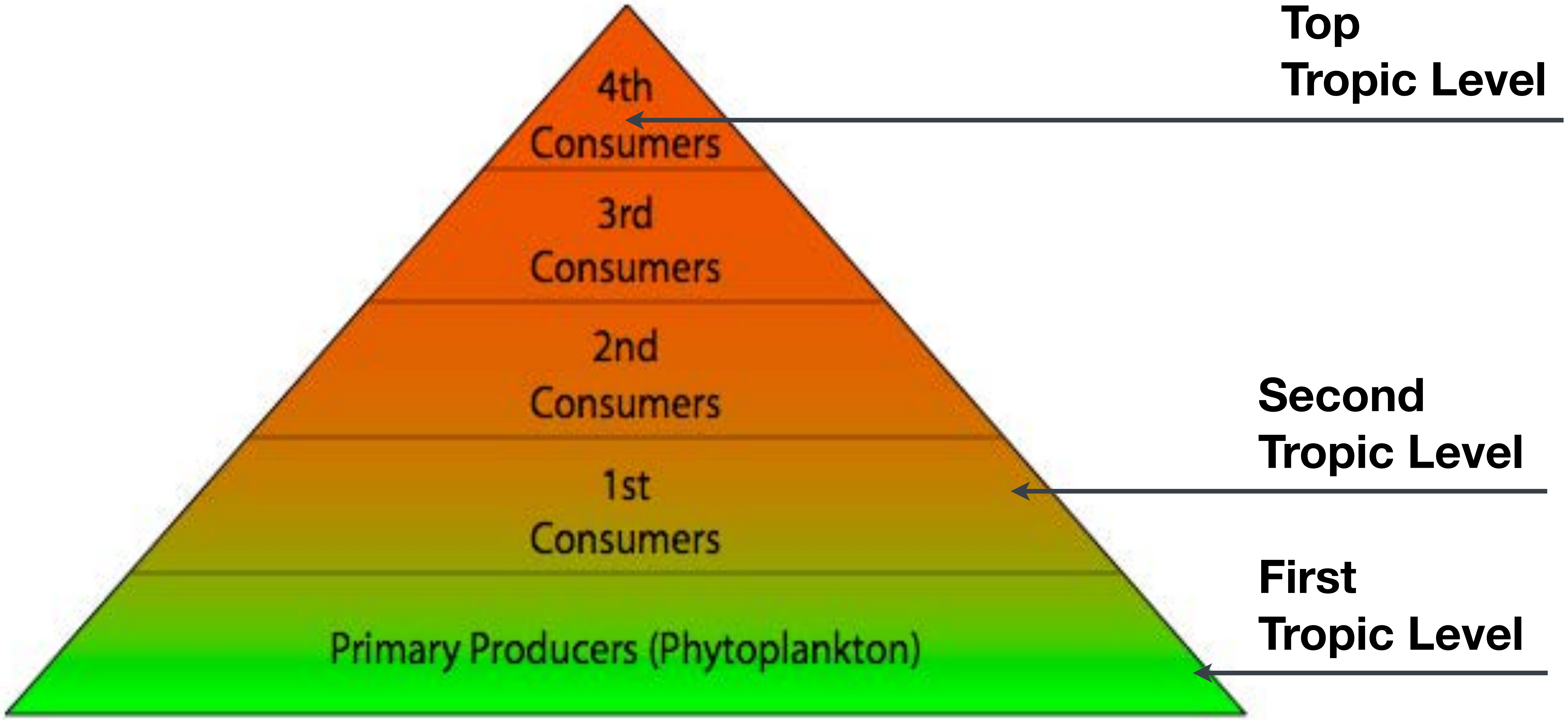
- **It determines who will eat it** (all organisms 10 times bigger than it)
- **It determines who it will eat** (all organisms 1/10 its own size)

**Pelagic Food Webs are Said to be Strongly Size-Structured!**

Using **Chlorophyll** and **Body Size** Allows Us to Go From This…



# To This!


4th
Consumers
3rd
Consumers
2nd
Consumers
1st
Consumers
Primary Producers (Phytoplankton)
Top
Tropic Level
Second
Tropic Level
First
Tropic Level

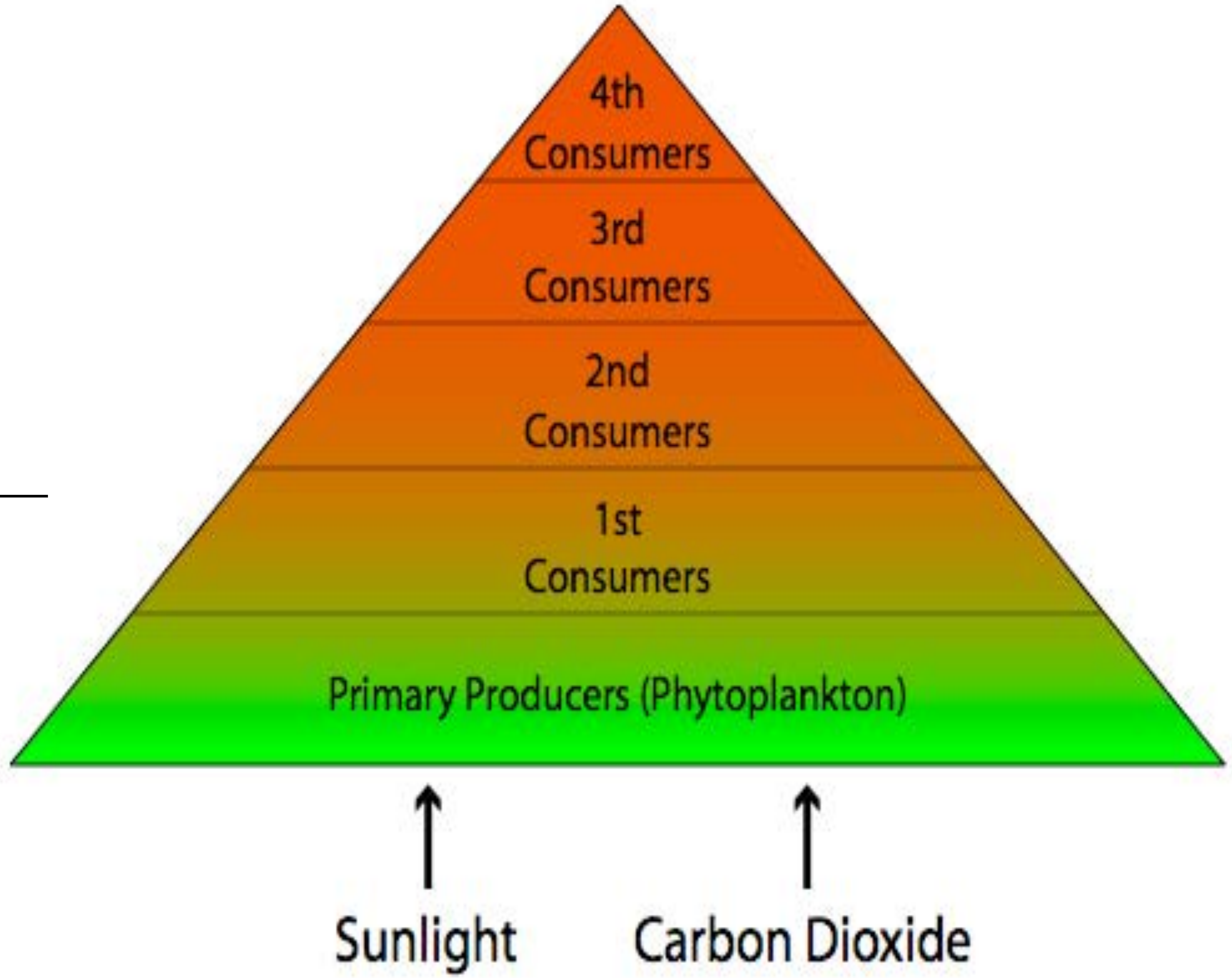
# Section II

Trophic Transfer Efficiency

# Trophic Transfer Efficiency

What determines the efficiency of carbon or energy transfer from one trophic level to another?

***i.e., the trophic transfer efficiency***



# The Overall Trophic Transfer Efficiency Depends on Two Factors:

**1. Exploitation Efficiency**

The efficiency with which a consumer population is able to **find, capture and ingest** all of the potential prey present in the environment

**2. Gross Production Efficiency**

The physiological/biochemical efficiency of **converting ingested prey into consumer biomass**

**3. Trophic Transfer Efficiency=** (Exploitation Efficiency x Gross Production Efficiency)

**For example,** if exploitation efficiency was (hypothetically) 50% and gross production efficiency was (hypothetically) 50% then…

**Trophic Transfer Efficiency= 0.5 x 0.5 = 0.25 = 25%**

# Exploitation Efficiency

(Find, Capture and Ingest Prey)

A Game of Hide and Seek….

# **Exploitation Efficiency** *(a game of hind and seek)*

It's kind of rough living in the ocean where organisms have to be good at finding and ingesting prey AND also be good at not becoming prey themselves!

Evolution has worked long and hard to create some pretty elaborate strategies for this game of hide and seek in the ocean...

1. strategies for detecting prey
2. strategies for capturing prey once detected
3. counter strategies to avoid detection in the first place
4. counter strategies to frustrate capture if detected

# Strategies for Finding Prey

- **Locomotion**
  - Cruising -- rely on your own locomotion to encounter prey
  - Ambush -- rely on the locomotion of your prey to come to you
- **Perception**
  - Visual perception
  - Mechanosensory
  - Chemosensory

# Strategies for Capturing Prey

- **Raptorial**
  - grasp prey with appendages
- **Direct interception**
  - bump into prey and engulf
- **Filtering**
  - sieve large volumes of water
- **Entanglement**
  - set net or trap

# Strategies to Avoid/Escape Predation

- **Avoid Encounters or Detection**
  - remain motionless
  - be transparent
  - **separate by time and/or space**

- **Frustrate the Capture Process**
  - be very small or large size -- refuge from predation
  - spines -- mechanical defense
  - escape response
  - schooling

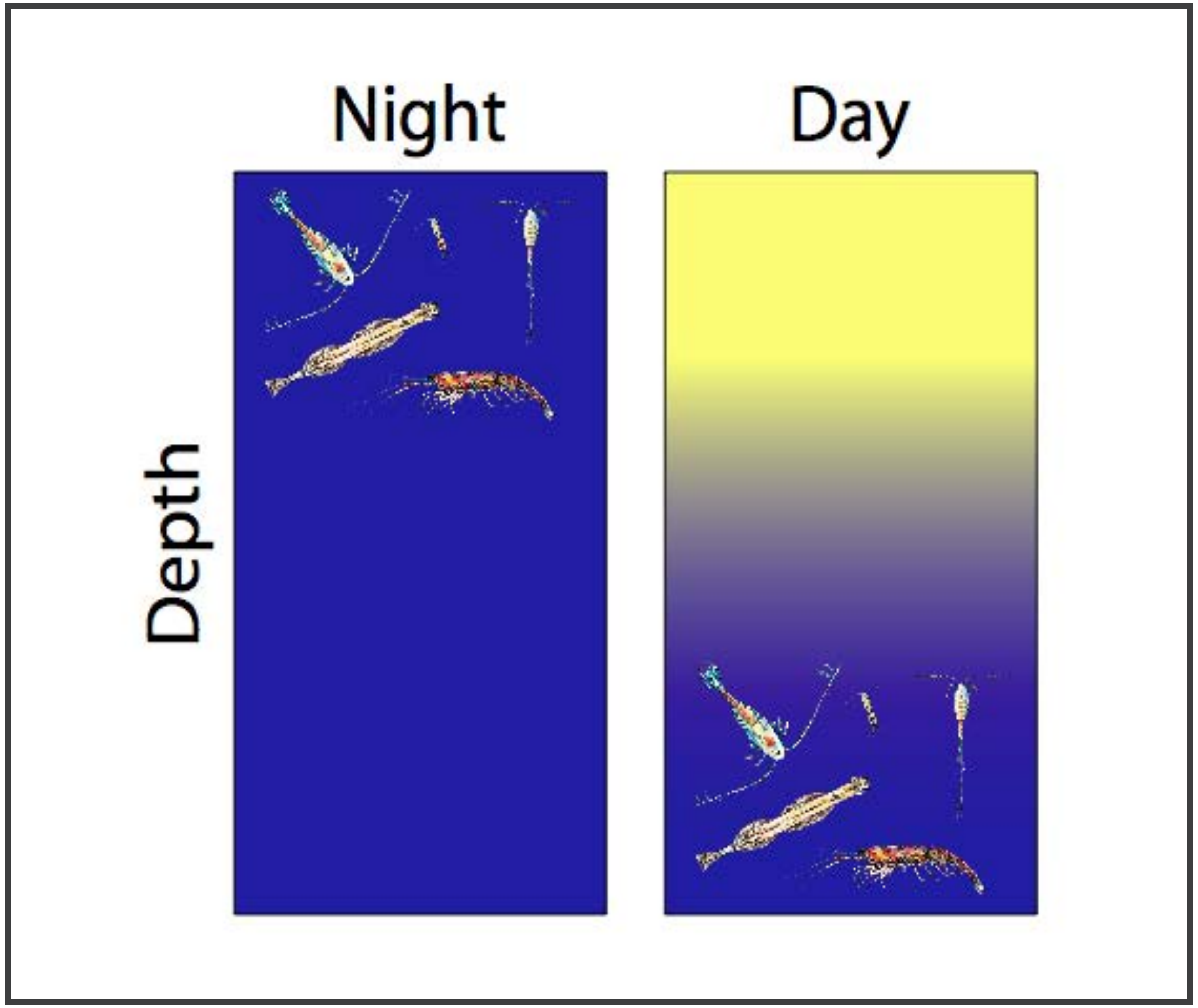
Many zooplankton species exhibit **bioluminescence** (short-term bursts of light). One theory for its existence is predator avoidance. Creating a large flash of light as a predator approaches momentarily stuns and confuses the predator long enough for the prey species to make its escape.

# Diel Vertical Migration

## Avoid Detection by Separation in Time

Much of the zooplankton community migrates up to the surface layer of the ocean at night to feed in the dark while also avoiding visual predators like small fish.

During the day zooplankton migrate down to the safety of the darkness found at depth.



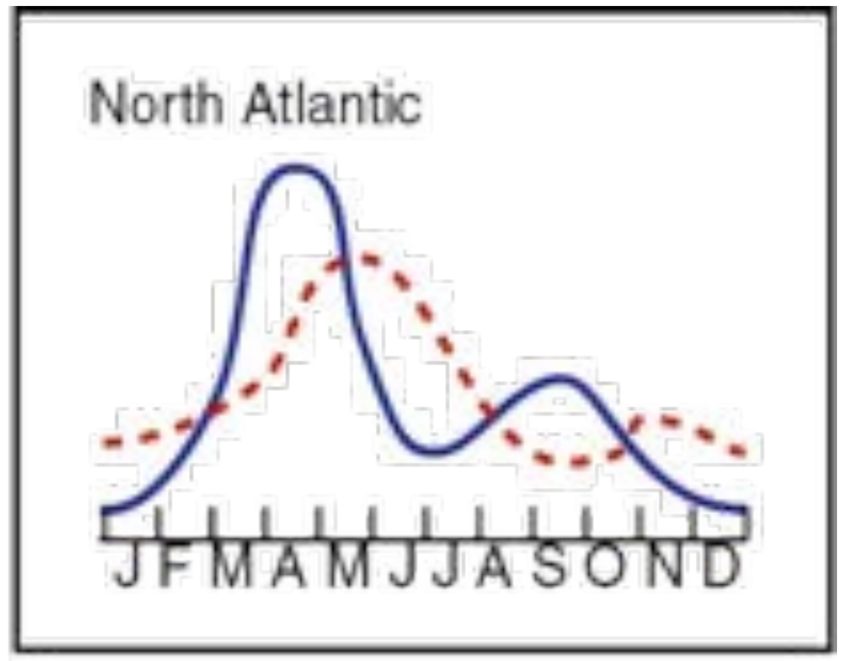
# Examples of Two Very Different Grazer Exploitation Efficiencies in Two Very Different Ocean Environments…

## A. Spring Blooms in the Temperate North Atlantic Region:

1. **During long winter periods large grazers** (copepods mainly) sink into the deep ocean and enter a diapause (i.e., hibernation) stage and thereby become ***decoupled*** from any variations in primary production above.
2. **In spring**, phytoplankton standing stock can initially grow to very high density because it is not held in check by strong grazing pressure (*phytoplankton growth is decoupled from grazing*) until the large grazers have a chance to come out of diapause, grow and reproduce to the high numbers needed to control increases in phytoplankton abundance.
3. This allows for exceptional phytoplankton blooms during the decoupled period.

**Exploitation Efficiency is Very Low**

much of phytoplankton is not found by grazers and instead sinks into the deep ocean as dead phytoplankton cells



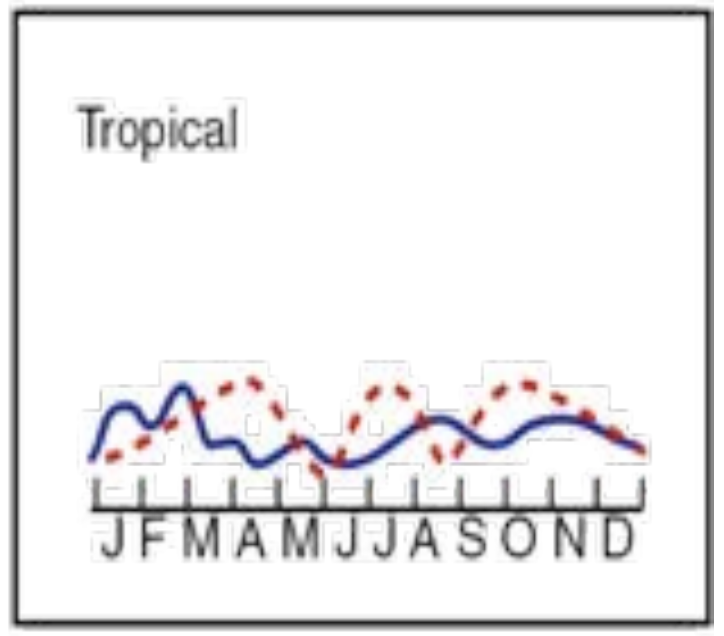

phytoplankton
zooplankton

## B. Tropical Environments:

1. **Small grazers** remain active throughout the year and consume phytoplankton as fast as it is made.
2. Any increase in production is quickly met by an increase in grazer abundance and subsequent increase in the consumption of phytoplankton.
3. This leaves standing stock of phytoplankton nearly constant throughout the year

**Exploitation Efficiency is Very High**

almost all phytoplankton is found and consumed by grazers




phytoplankton
zooplankton

# Exploitation Efficiency: Main Points

**Exploitation Efficiency** expresses the efficiency with which members of a given trophic level are able to find, capture and ingest members of the next lower trophic level

Exploitation Efficiency can range greatly (10% and 90%) depending on the particular trophic interaction in question. For example

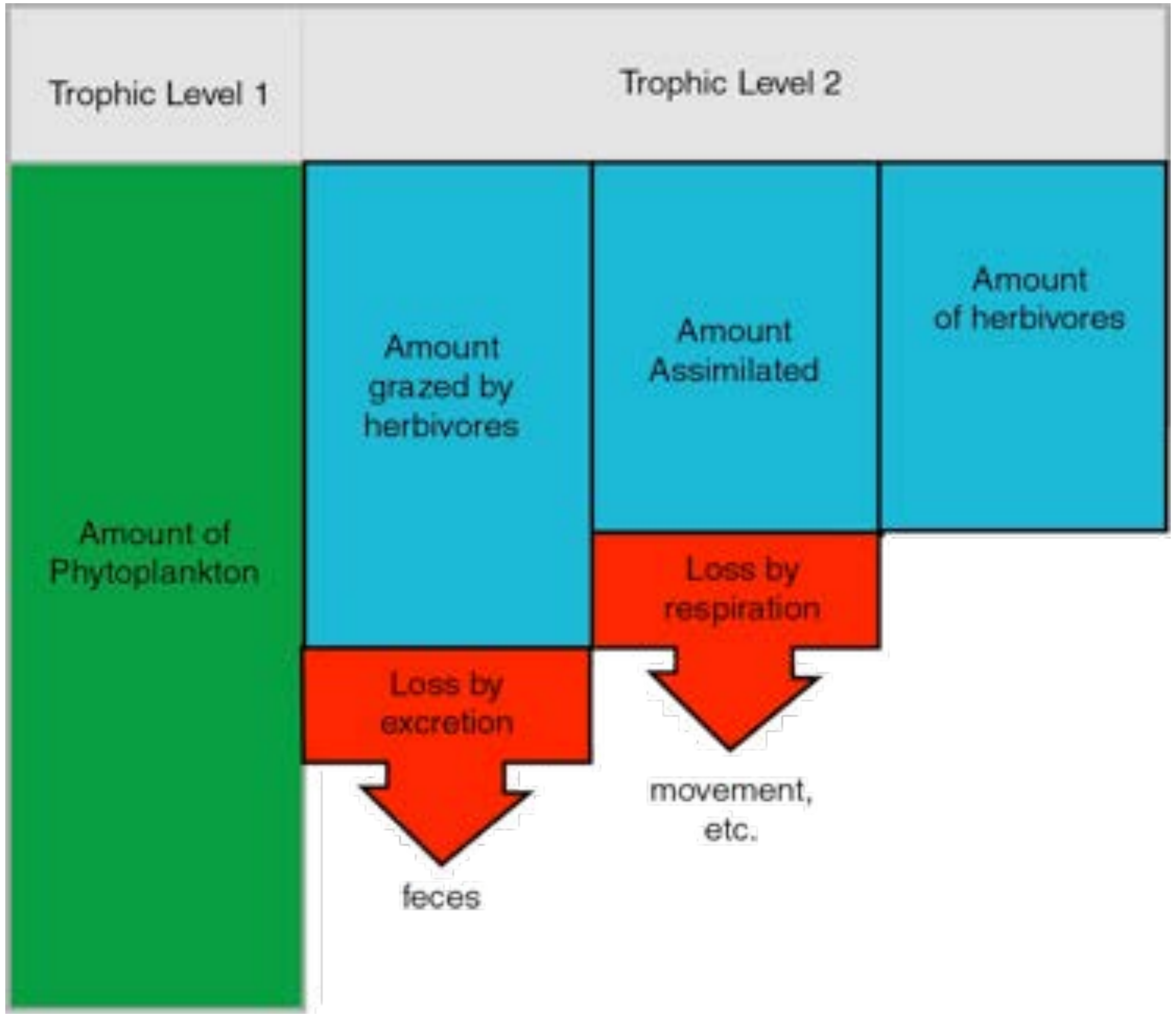
- In the case of **tropical oceans** where grazing is tightly coupled to primary production, the grazers find and ingest almost all of the phytoplankton cells. Consequently, exploitation efficiency of grazers **is high**
- In the case of the **early part of the spring bloom** in the North Atlantic, much of the phytoplankton does not get ingested and instead sinks to the bottom of the ocean. Consequently, exploitation efficiency of grazers **is low during this period**.

# Gross Production Efficiency

The amount of consumer biomass produced divided by amount of prey biomass consumed.

This efficiency ranges between 20% and 60%

## Diagram of a Material Budget for a Primary Consumer



# Trophic Transfer Efficiency Summary

1. **Trophic Transfer Efficiency** is a Function of:
    - **Exploitation Efficiency (10% to 90% )**
    - **Gross Production Efficiency (20% to 60%)**

2. The combined effect of both exploitation and gross production efficiencies yields an overall trophic transfer efficiency of **about 10% to 20%**

**For the remainder of the lecture we will make things simple and use a flat 10% trophic transfer efficiency...**

# Question

Suppose you had phytoplankton production of **1000 biomass units per year** and you had a food chain with 3 trophic steps between phytoplankton and the fish that you wanted to catch each year…

**phytoplankton --> zooplankton --> small fish --> your fish**

**1000 100 10 1**

How much fish production would you expect each year if tropic transfer efficiency is 10% for each trophic step?

a) 1000 biomass units of fish per year

b) 100 biomass units of fish per year

c) 10 biomass units of fish per year

d) 1 biomass units of fish per year

# Marine Food Chains: Summary

1. Marine food chains are strongly size-structured. You can determine who-eats-who based mainly the size of the organisms.

2. **Trophic Transfer Efficiency** = percentage of lower trophic level biomass or energy that is transferred to the next higher trophic level's biomass or energy. **It is a function of exploitation efficiency and gross production efficiency.**
   - **Exploitation Efficiency** (predator-prey interaction strategies)
     - The Efficiency ranges widely (10% to 90%) depending on the interaction in question.
   - **Gross Production Efficiency** (converting ingested prey food into consumer biomass)
     - The Efficiency ranges from 20 to 60%.

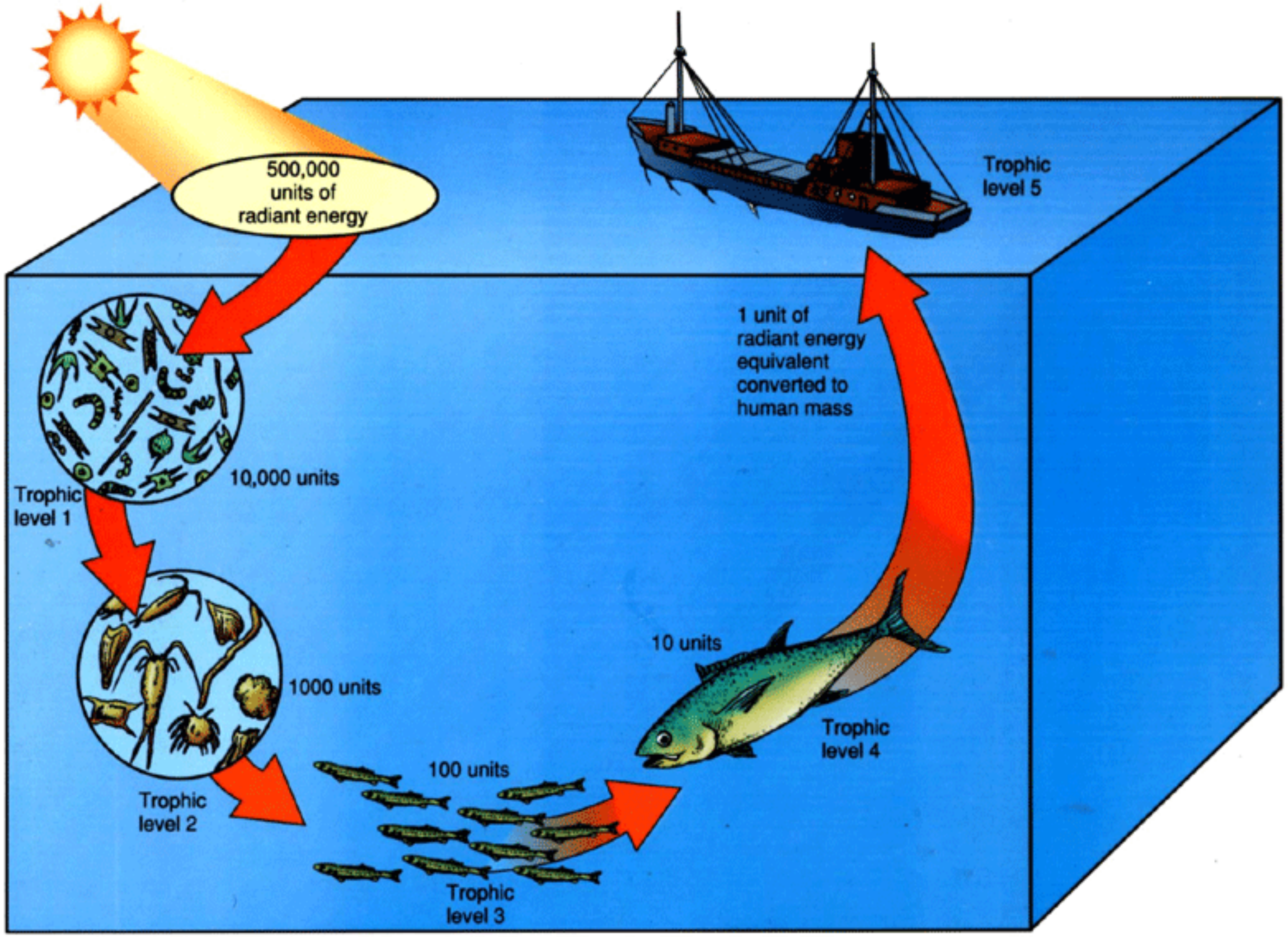
3. Overall Trophic Efficiency (Exploitation + Gross Production) ranges from 10% to 20%.

# Section III

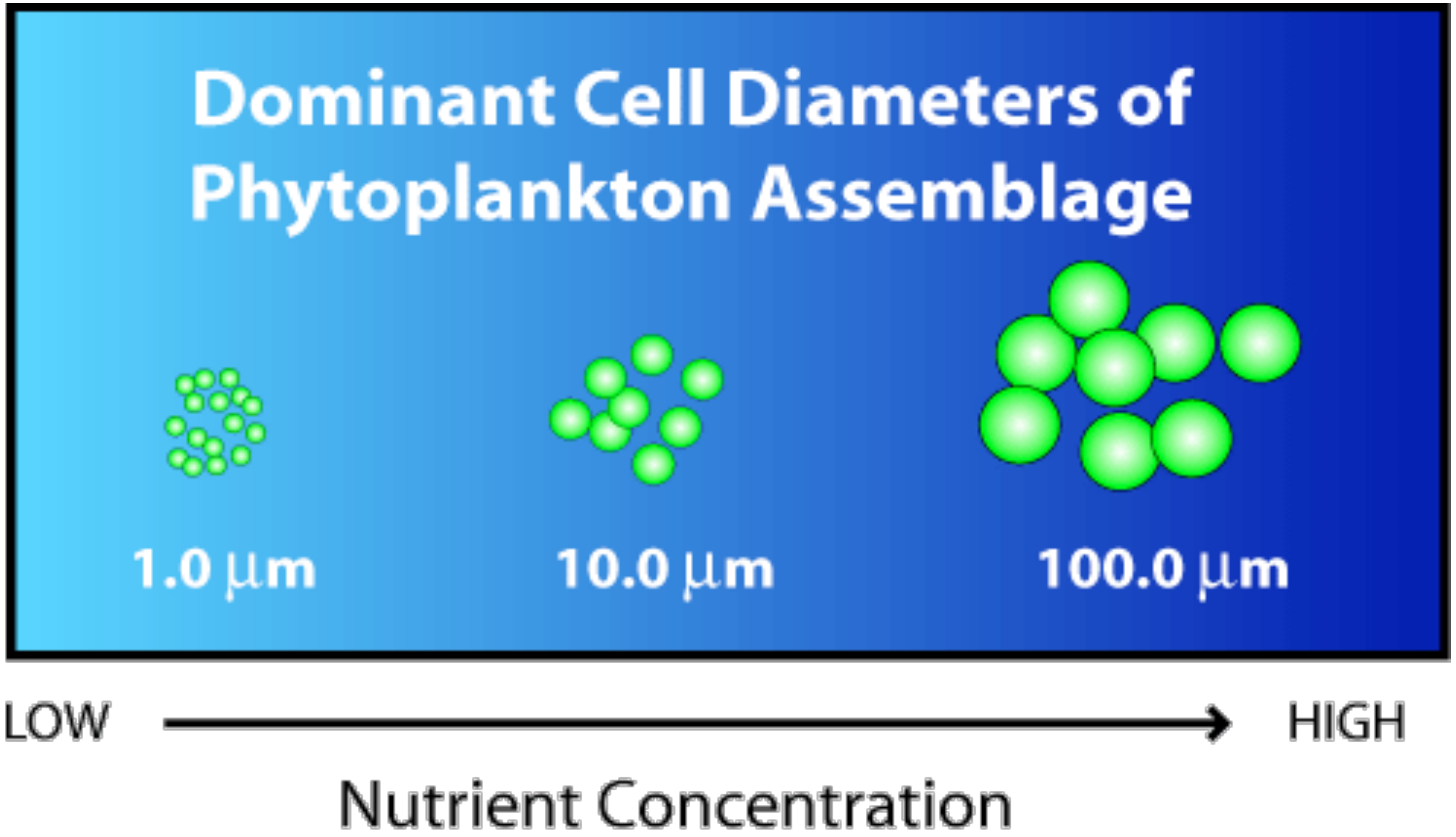
## The Consequences of a Food Chain Length on Upper Limit of Fisheries Production

# Trophic Transfer Efficiency and Harvestable Yield

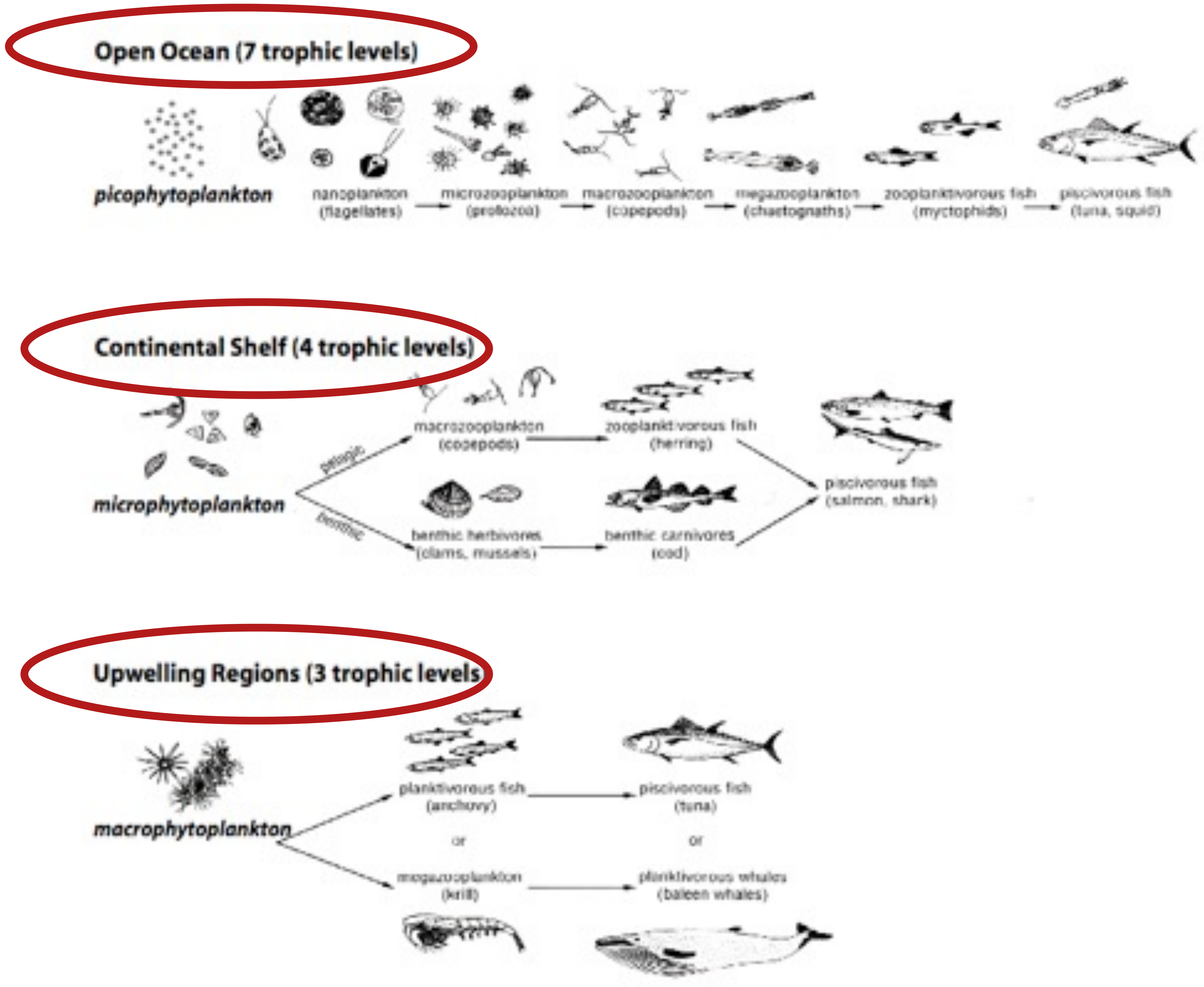
This example assumes 10% trophic transfer efficiency



Recall from the primary production lectures that small cells have the growth advantage at low nutrient conditions - **This fact is vitally important!**



# Food Chain Length of Open Ocean versus Coastal Upwelling Regions




**Low Nutrient Open Ocean:**
**Phytoplankton are small** and the number of trophic levels/steps to harvestable fish are many — big overall loss due to many trophic transfer steps

**High Nutrient Coastal Upwelling:**
**Phytoplankton are large** and the number of trophic levels/steps to harvestable fish are few — small overall loss due to few trophic transfer steps

# Highest Production of Harvestable Fish is in Coastal Upwelling Regions

| Oceanic Province | Primary Production ($10^6$ g yr$^{-1}$) | Trophic Transfer Efficiency | Trophic Level Harvested conservative estimate | Estimated Fish Production ($10^6$ g yr$^{-1}$) |
|---|---|---|---|---|
| **Open Ocean** | $39.9 \times 10^9$ ✓ | 10% | 7✓ | $4.0 \times 10^3$ |
| **Upwelling Areas** | $0.23 \times 10^9$ ✓ | 20% | 2✓ | $46.0 \times 10^6$ |

**The specific numbers above are <u>not</u> so important. What <u>is</u> important is this...**

1. **The Open-Ocean Region** comprises most of the global ocean primary production, but phytoplankton in this low-nutrient region are small and so **<u>there are a lot of trophic steps (7 steps) to get to harvestable fish</u>** and each trophic step reduces carbon biomass production by 1/10 so for 7 steps there is a $1/10^7$ reduction altogether.
2. **The Coastal Region** has less overall primary production, but it <u>benefits greatly</u> by having **<u>just 2 trophic steps to harvestable fish</u>** which makes for very efficient transfer of carbon from primary producer to harvestable fish in this high-nutrient region **and so it is this region that is the most productive for fish...**

# Summary

The upper limit on the total biomass of harvestable fish in a given ocean province is determined by:

1. Intensity of primary production per square meter in the ocean province and areal extent of the ocean province

2. Number of trophic levels between primary producers and the harvestable fish in the ocean province and the trophic transfer efficiencies between each of trophic levels

# Summary

## Open Ocean Province

Low primary productivity per square meter, but areal extent is so large that it has the greatest overall primary production of any province, BUT phytoplankton are small in this province so the number of trophic steps is large (up to 7-total) and the loss of (up to $1/10)^7 = 1/10{,}000{,}000$ to get to harvestable fish, does not make up for the large overall primary production and thus yields small fish production.

## Upwelling Province

High primary productivity per square meter, but small areal extent so small the total primary production for this province is low, BUT phytoplankton are large and so the number of trophic steps to get to harvestable fish is small (2-total) so the loss of just $(1/10)^2 = 1/100$ and this overall transfer efficiency makes up for the relatively small overall primary production to then yield the highest of fish production in this province