

2021 NCF-Envirothon Nebraska Aquatic Ecology Study Resources

Key Topic #1: Aquatic Species

1. Identify different aspects of fish anatomy and explain their functions.
2. Describe the various roles that fish play in different types of ecosystems.
3. Identify common Nebraska fish species.
4. Identify invasive aquatic species in Nebraska.

Study Resources

Structure and Function: Fish – *University of Hawai'i, 2021* (Pages 2 - 13)

Fish Identification – *Nebraska Game and Parks Commission, 2021* (Pages 14 - 17)

Aquatic Invasive Species – *Nebraska Game and Parks Commission, 2021* (Pages 18 - 19)

Study Resources begin on the next page!



Structure and Function – Fish

University of Hawai'i, 2021

External Anatomy of Fishes

Anatomy is the study of an organism's structures. Fishes come in a diverse array of forms, many with special modifications. The shape, size, and structure of body parts permit different fishes to live in different environments or in different parts of the same environment. The external anatomy of a fish can reveal a great deal about where and how it lives.

When describing the basic anatomy of an organism, it is useful to have some common terms to help with orientation. Just as a map uses north, south, east, or west to help determine the location, orientation words are useful in describing anatomy. Table 4.3 defines common anatomy terms, Fig. 4.18 shows their orientation on three different animals.

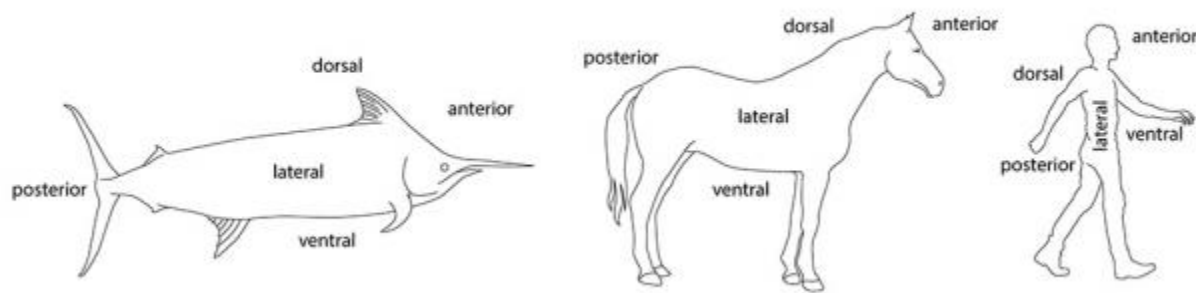


Fig. 4.18. Common orientation terms applied to three different animals: a billfish, a horse, and a person. (Image by Byron Inouye)

Table 4.3. Anatomy position words

Anatomy Word	...of the organism
Anterior	The head end...
Posterior	The tail end...
Dorsal	The back
Ventral	The front or belly
Lateral	The side or flank

Scientists measure and describe the external features of fishes to identify species, assess age and health, and learn about structure and function. Scientists work with a variety of types of fishes to do this. They might use a fresh fish, or they may use photographs, scientific drawings, or other kinds of detailed images—even fish fossils.



Fig. 4.19. A *gyotaku* print of a longtooth grouper (Image courtesy of J.G. Wang, [Flickr](#))

One way to document details about a fish is *gyotaku*. **Gyotaku** (pronounced *gee yo TAH koo*) is a traditional Japanese method of printmaking, which uses the whole fish. This method can produce an accurate image of a fish (Fig. 4.19).

Gyotaku is a relatively new art form that developed in Japan, probably in the early- to mid-nineteenth century. *Gyotaku* means ‘fish rubbing.’ *Gyotaku* is valued from both a scientific and artistic perspective. The detail captured in *gyotaku*, especially in historical prints, is an important source of information for scientists who want to know the size and external features of fish in the past. The color and artistic arrangement of *gyotaku* prints made by skilled artists also make them valuable pieces of art. The oldest known *gyotaku* print, made in 1862, is owned by the Homma Museum in Sakata, Japan.

Body Form

Perches are the most common type of bony fishes. As a result, people often use the words *perch-like* to describe a generic fish shape. (Fig. 4.21 A). Fusiform is the scientific term used to describe the perch’s streamlined, torpedo shaped body. **Compressiform** means laterally flattened (Fig. 4.21 B). **Depressiform** means dorso-ventrally flattened (Fig. 4.21 C). **Anguilliform** means eel-like (Fig. 4.21 D). See Table 4.4 for additional descriptions of fish body shapes.



Fig. 4.21. (A) Perch (fusiform-torpedo shape)
U.S. Department of Agriculture ([USDA](#))



Fig. 4.21. (B) Angelfish (compressiform- flat side to side) ([NOAA](#))

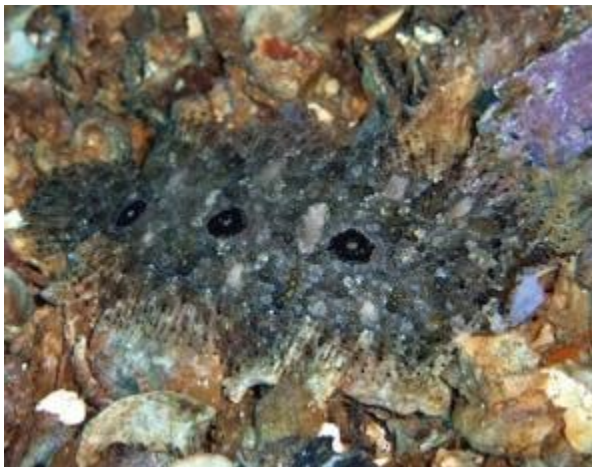
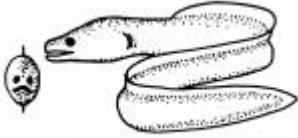

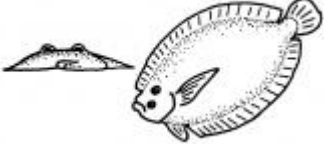




Fig. 4.21. (C) Flounder (depressiform - flat top to bottom) (*Katie Samuelson*)



Fig. 4.21. (D) Eel (anguiliform-eel like)
(*Drow male*)

Table 4.4. Fish form and function: body shape (*Images by Byron Inouye*)

Diagram of Body	Description	Adapted Function
	Anguilliform (eel shape)	Maneuvering in crevasses
	Fusiform (bullet, or torpedo shape)	Lowering frictional resistance in fast swimmers
	Depressiform (broad shape and flat top to bottom)	Lying on or below the surface of the sand
	Compressiform (tall, thin shape and flat side to side)	Entering vertical crevices
	Elongated shape that is somewhat anguilliform (eel shape)	Ambush predators

Fish Fins

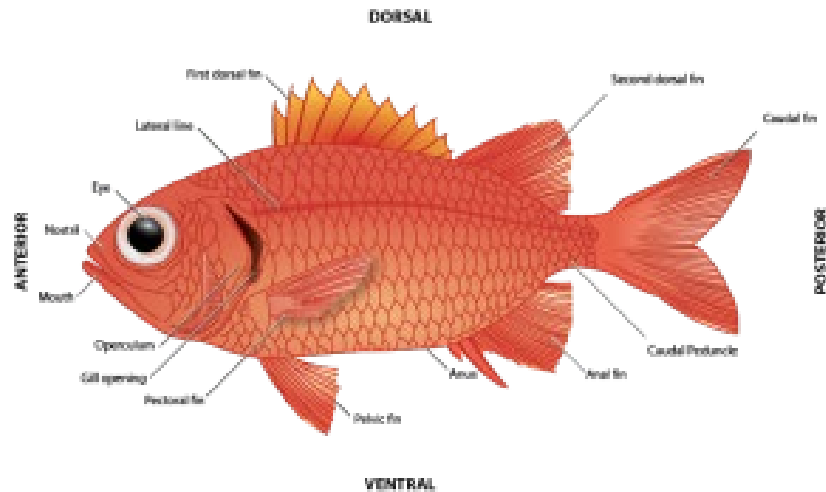

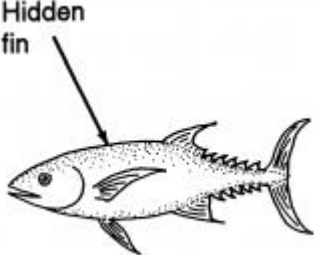
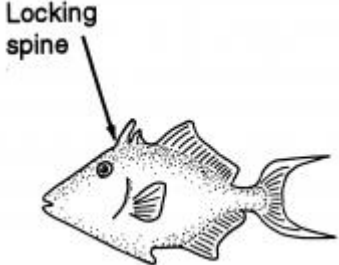
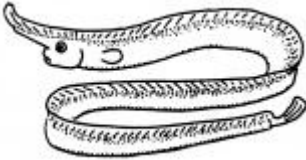




Fig. 4.9. (B) Anatomy of a soldierfish, *Myripristis berndti* (Image by Byron Inouye)

The first anatomical structures many people identify on a fish are the fins. In fact, “appendages, when present, as fins” is part of one of the scientific definitions of a fish. Most fish have two kinds of fins: median and paired.

Median fins are single fins that run down the midline of the body. The dorsal fin is a median fin located on the dorsal side of the fish. The anal fin and caudal fin are also median fins. **Paired fins** are arranged in pairs, like human arms and legs. The pelvic and pectoral fins are both paired fins. (Table 4.5).

Table 4.5. Fish form and function: dorsal fin features (*Images by Byron Inouye*)

DORSAL FIN DIAGRAM	DESCRIPTION	ADAPTED FUNCTION
	Spiny and soft-rayed dorsal fin.	Flared to make the fish look bigger
	Tucked dorsal fin	Reduces drag in fast swimming fish
	Locking spiny dorsal fin	Locking fish into coral crevices
	Very long dorsal fin	Snake-like locomotion
	Three dorsal fins	Locomotion
	No dorsal fin	Snake-like locomotion

Median Fins

Median fins, like the dorsal, anal, and caudal fins, can function like the keel of a boat and aid in stabilization (Fig. 4.22 A). Median fins can also serve other purposes, like protection in the lion fish (Fig. 4.22 B).



Fig. 4.22. (A) The keel of boat stabilizes the boat, similar to a fish's anal fin
(Image courtesy of Brother Magneto Flickr)



Fig. 4.22.(B) The dorsal fin of a lionfish has spines and poison for protection
(Image courtesy of Katie Samuelson)

Caudal (Tail) Fin

The **caudal fin** is known commonly as the tail fin (Table 4.6). It is the primary appendage used for locomotion in many fishes. The caudal fin is also a median fin (Fig. 4.22 A).

The **caudal peduncle** is the base of the caudal fin. Peduncle means stem, and the caudal peduncle is where the strong swimming muscles of the tail are found. Together, the caudal fin acts like a “propeller” for the fish, and the caudal peduncle acts like a motor.

Table 4.6. Fish form and function: Caudal fin features (*Images by Byron Inouye*)

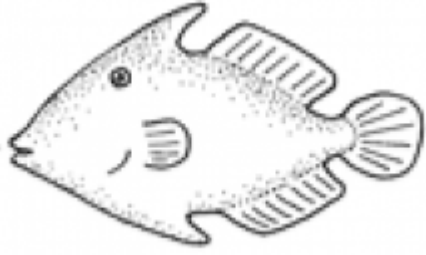
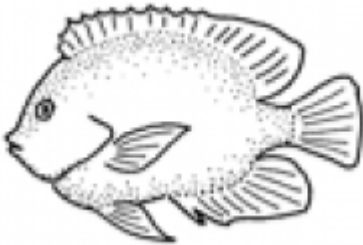
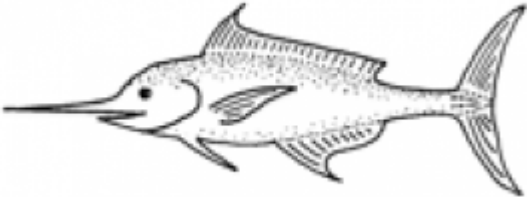
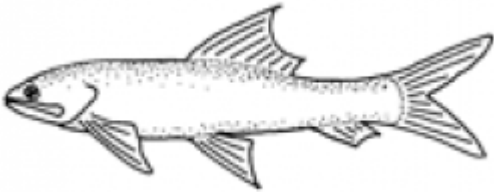

Tail Diagram	Description	Adapted Function
	Rounded tail	Slow swimming, accelerating, and maneuvering
	Truncated (triangular) tail	Turning quickly
	Lunate (moon shaped) tail	Continuous long distance swimming
	Forked tail	Rapid swimming, somewhat sustained with bursts of speed
	Heterocercal (taller upper lobe) tail	Slow or rapid swimming with bursts of speed



Fig. 4.25. (A) trout showing two dorsal fins on top and, from left to right, pectoral, pelvic, and anal fins
(Photo courtesy of the Wild Center [Flickr](#))



Fig 4.25. (B) wrasse
(Photo courtesy of Katie Samuelson)

Ampullary receptors

Ampullary receptors are sense organs made of jelly-filled pores that detect electricity. They can detect low frequency alternating current (AC) and direct current (DC). Ampullae detect electricity emitted by prey as well as the small electrical fields generated by a fish's own movement through the earth's magnetic fields. Researchers think that this may help fishes use the Earth's magnetic field for navigation. Fishes that have ampullae include sharks, sturgeon, lungfish, and elephant fish. The ampullae of sharks are known as Ampullae of Lorenzini—named for Stefano Lorenzini, who first described them in 1678 (Fig. 4.33).

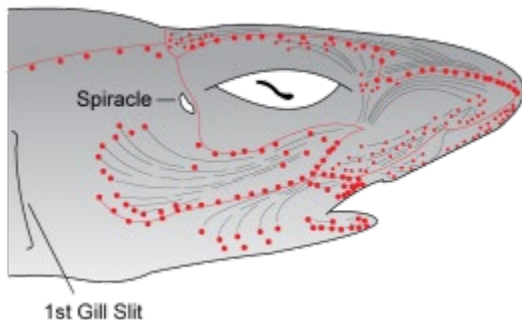


Fig 4.33.(A) Ampullae of Lorenzini in a shark's head (Image courtesy of Chris Huh)



(B) Ampullae of Lorenzini pores on the snout of a tiger shark
(*Image courtesy of Albert Kok*)

Some fishes can also generate their own electrical fields. These fishes have both ampullae type receptors and tuberous type receptors. The tuberous receptors are most sensitive to the electric organ discharge of the fish itself, which is important for object detection. The tuberous type of receptor is usually deeper in the skin than ampullae.

Some fishes that produce electricity also use it for communication. Electric fishes communicate by generating an electric field that another fish can detect. For example, elephant fishes use electrical communication for identification, warning, submission, courtship, and schooling (Fig. 4.34).



Fig 4.34 The elephant fish use electric impulses to communicate.

Body Coverings

One definition of a fish includes “body usually covered with scales.” Except for some parts of the head and fins, the bodies of many fishes are covered with overlapping scales (Fig. 4.41). **Scales** generally serve to protect the fish’s skin.



Fig. 4.41. The overlapping scales of a roach fish (*Rutilus rutilus*)
(Image by *kallerna*)

Different fishes have different types of scales. These different types of scales are made of different types of tissue (Fig. 4.42 and Table 4.15). Types of scales also correspond to evolutionary relationships (Fig. 4.9).

Placoid scales are found in the sharks and rays (Fig. 4.42 A). Placoid scales are made of a flattened base with a spine protruding towards the rear of the fish. These scales are often called dermal denticles because they are made from dentin and enamel, which is similar to the material teeth are made of.

Ganoid scales are flat and do not overlap very much on the body of the fish (Fig. 4.42 B). They are found on gars and paddlefishes. In the sturgeon, ganoid scales are modified into body plates called scutes.

Cycloid and Ctenoid scales are found in the vast majority of bony fishes (Figs 4.42 C and 4.42 D). These types of scales can overlap like shingles on a roof, which gives more flexibility to the fish. These scales also form growth rings like trees that can be used for determining age. Ctenoid scales are different than cycloid scales in that cycloid scales tend to be more oval in shape. Ctenoid scales are more clam shaped and have spines over one edge. Cycloid scales are found on fishes such as eels, goldfish, and trout. Ctenoid scales are found on fishes like perch, wrasses, and parrotfish. Some flatfishes, like flounder, have both cycloid and ctenoid scales.

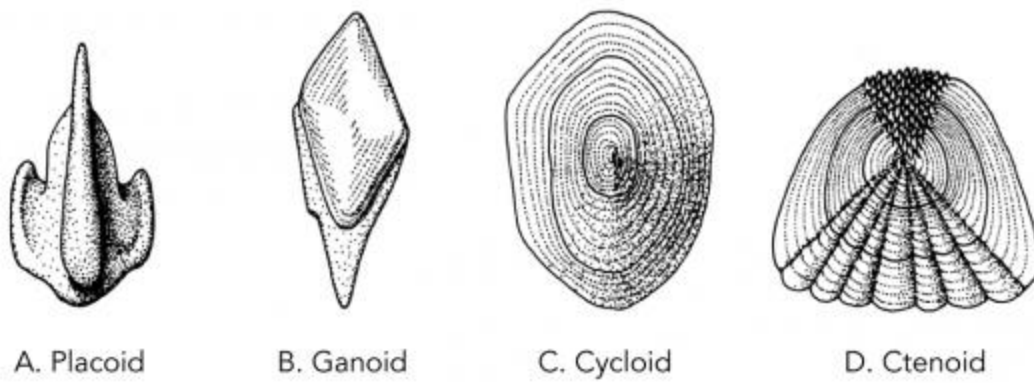


Fig. 4.42. Four types of fish scales A) Placoid, B) Ganoid, C) Cycloid, and D) Ctenoid

Image from Living Ocean, CRDG, University of Hawaii at Manoa

Fish Identification

Nebraska Game and Parks Commission, 2021

Channel Catfish

Ictalurus punctatus

Also known as: fiddler

Family: Catfish

Type: Sport Fish

Range: Statewide



Description: An olive-brown or slate-blue, scaleless fish having dark spots (especially on small fish), an adipose fin, 8 barbels that are used to locate food, and a deeply forked tail. Its anal fin has 24-29 rays with a rounded margin. Breeding males become dark blue and are often misidentified as a blue catfish. Many anglers are mistaken by thinking they can be stung by the whiskers (barbels). What they have to avoid are the hard spines (one in the dorsal fin and one in each pectoral fin) that can inflict a puncture wound if the fish is mishandled. Primarily bottom-feeder, consuming living or dead items. Diet is varied and includes fish, crayfish, insects, mollusks, and plant material. One of the top five commonly sought-after sport fish in the state.

Flathead Catfish

Pylodictis olivaris

Also known as: flathead, shovelhead, yellow cat

Family: Catfish

Type: Sport Fish

Range: Eastern and southwestern Nebraska



Description: A scaleless fish having a broad flat head with a projecting lower jaw, an adipose fin, 8 barbels that are used to locate food, and a tail fin with a squarish margin. Pale yellow to light brown colored, often mottled with dark brown or black if from clear water. Many anglers are mistaken by thinking they can be stung by the whiskers (barbels). What they have to be aware of are the hard spines (one in the dorsal fin and one in each pectoral fin) that can inflict a puncture wound. Primarily a nocturnal predator, feeding at or near the bottom – rarely eats dead or decaying matter. Smaller flatheads mostly eat aquatic insects while larger flatheads primarily consume fish and crayfish.

American Eel

Anguilla rostrata

Also known as: eel

Family: Eel

Type: Sport Fish

Range: Missouri River, lower portion of Platte River



Description: Snake-like body with continuous dorsal, tail and anal fin. It is a “catadromous” fish – it lives in freshwater but spawns in saltwater. Only females migrate this far inland. Become mature in 6 to 20 years, then migrate back to Bermuda area of Atlantic Ocean (often referred to as the Sargasso Sea) where they spawn and die. Aquatic insects are the main food of small eels, while large eels mainly consume fish, frogs and crayfish. Seldom caught by anglers.

Longnose Gar

Lepisosteus osseus

Also known as: gar

Family: Gar

Type: Non-Game Fish

Range: Larger rivers and associated sandpits of eastern Nebraska



Description: Primitive fish having a rounded tail fin; hard plate-like, non-overlapping scales; and a long, slender, beak-like bony snout with sharp teeth. Thrives in warm, sluggish backwaters that have oxygen levels too low for most other fishes since its swim bladder is connected to the throat and can function much like a lung. It stalks its prey and often captures it with a quick flick of its head – capturing the prey sideways; once struggling has ceased, the prey is turned in the jaws and swallowed head first. Diet consists almost entirely of fish. Seldom caught by anglers.

Shortnose Gar

Lepisosteus platostomus

Also known as: gar

Family: Gar

Type: Non-Game Fish

Range: Large and medium-size rivers of eastern Nebraska and associated sandpits



Description: Primitive fish having a rounded tail fin; hard plate-like, non-overlapping scales; and a moderately short, broad, beak-like bony snout with sharp teeth. Our most common gar and is most tolerant of muddy water. Has the ability to utilize its swim bladder much like a lung which allows it to survive in waters with low oxygen levels. Has a more diverse diet than longnose gar – consisting of insects and crayfish in addition to fish. Seldom caught by anglers.

Chestnut Lamprey

Ichthyomyzon castaneus

Also known as: lamprey

Family: Lamprey

Type: Non-Game Fish

Range: Scarce, some have been found in the Missouri River



Description: Parasitic fish with eel-like body and a sucking-disc mouth that enables it to cling onto host fish. The teeth on the tongue-like structure are then used to rasp into the flesh which enables the lamprey to feed on body fluids that flow from the wound. Many fish survive the attack – as evidenced by a scar. Lampreys migrate upstream to find favorable spawning sites.

Paddlefish

Polyodon spathula

Also known as: spoonbill

Family: Paddlefish

Type: Sport Fish

Range: Primarily the Missouri River; can also be found in portions of the Platte River and some nearby sandpits



Description: Shark-like body with an elongated, paddle-like snout (rostrum). It is from a primitive family of freshwater fishes and is represented by only two living species – the other one can be found in the Yangtze Valley in China. Paddlefish feed by swimming slowly through areas where food items (microscopic plants and animals) are concentrated, mouth wide open, filtering water as it passes through specially-designed gill rakers. Spawning can occur in free-flowing river regions containing gravel bars that remain underwater during the entire spawning season. Snagging (during season) is usually the way anglers capture them.

Pallid Sturgeon

Scaphirhynchus albus

Also known as: sturgeon

Family: Sturgeon

Type: Endangered Fish

Range: Missouri River, lower portions of the Platte and Elkhorn Rivers



Description: Primitive fish having several rows of thorny scales or plates and 4 barbels near its mouth which is located far back under the long, pointed snout. Barbels are fringed and lower lip has 4 lobes. Bases of outer barbels usually behind bases of inner barbels and belly without plates. Endangered species, illegal to possess. Feeding habits similar to lake sturgeon; however, diet primarily consists of aquatic invertebrates (primarily aquatic insects) and small fish (mostly

minnows). Natural reproduction has been documented in our stretch of the Missouri River. Some stockings have been done to bolster the population.

Shovelnose Sturgeon

Scaphirhynchus platyrhynchus

Also known as: sturgeon

Family: Sturgeon

Type: Sport Fish

Range: Missouri River and lower portions of major tributary streams/rivers.



Description: Primitive fish having several rows of thorny scales or plates and 4 barbels near its mouth which is located far back under the flattened, shovel-shaped snout. Barbels are fringed and lower lip has 4 lobes. Bases of outer barbels in line with or ahead of bases of inner barbels and belly is covered with small plates (except in young). In Nebraska, if a sturgeon weighs more than four pounds, it most likely is a pallid sturgeon. It is our most abundant sturgeon and is often caught by anglers. It feeds on the bottom, utilizing its barbels to locate food and protrusible mouth to suck up food items. Larvae of aquatic insects (primarily mayflies, true flies (Diptera), and caddisflies) make up the bulk of its diet.

Aquatic Invasive Species

Nebraska Game and Parks Commission, 2021

Aquatic Invasive Species (AIS) are exotic or non-native aquatic organisms that pose a significant threat to the aquatic resources, water supplies or water infrastructure of this state. These organisms can be plants, fish, mussels, crayfish, invertebrates or pathogens. Four categories have been established and can be changed upon Commission approval.

Category 1: Potential Aquatic Invasive Species

Category 1 invasive species are those that have not yet been sampled in Nebraska and are considered a high threat.

Currently listed as Category 1:

- Round Goby
- Snakehead (Federally banned)
- Black Carp
- Quagga Mussel
- New Zealand Mudsail
- Giant Reed
- Brazilian Waterweed or Elodea
- Hydrilla
- Brittle Nod
- Didymo (Rock Snot)
- White River Crayfish
- Red Swamp Crayfish

Category 2: Priority Aquatic Invasive Species

Category 2 invasive species are those that are currently present in Nebraska but with limited distribution. They are considered highly unwanted species and all efforts should be taken to prevent the expansion of their population.

Currently listed as Category 2:

- Silver Carp
- Bighead Carp
- White Perch
- Yellow Bass
- Asian Clam
- Zebra Mussel
- Waterflea
- Rusty Crayfish
- Curly-leaf Pondweed

- Flowering Rush
- Eurasian Watermilfoil
- Yellow Floating Heart
- Creeping Water Primrose

Category 3: Established Aquatic Invasive Species

Category 3 invasive species are those that are well established in Nebraska and total elimination is impossible. Local removal and control is the best that can be expected.

Currently listed as Category 3:

- Common Carp
- European Rudd
- Chinese Mystery Snail
- Japanese Mystery Snail
- Common Watercress
- Reed Canary Grass
- Narrow-leaf Cattail

Category 4: Aquatic Invasive Species listed as noxious in Nebraska

Category 4 invasive species are those that are regulated by the Nebraska Department of Agriculture as noxious plant species.

Currently listed as Category 4:

- Eurasian Common Reed (Phragmites)
- Salt Cedar
- Purple Loosestrife

2021 NCF-Envirothon Nebraska Aquatic Ecology Study Resources

Key Topic #2: Stream Habitats

5. Identify the order of a stream.
6. Describe how stream habitats and biological communities change with stream order.

Study Resources

Rivers and Streams: Life in Flowing Water – *Declan McCabe, Nature Education Knowledge, 2011* (Pages 21 - 32)

Strahler Stream Order – *United States Geological Survey, 2021* (Page 33)

Study Resources begin on the next page!



Rivers and Streams: Life in Flowing Water

Declan McCabe, *Nature Education Knowledge*, 2011

What lies beneath? Rivers: diverse habitats with broadly varying niches. Communities reflect and influence local, upstream, downstream, and broader landscape conditions.



Introduction

Water current pervades every facet of existence for life in **lotic** (flowing water) habitats. Maintaining position in the face of flow can be energetically costly, but provides access to a conveyor belt-like food-delivery system. Stream and river organisms reflect their localized niche, and surrounding landscape both upstream and downstream. River organisms have evolved in diverse and fascinating ways in the varied environments between river source and mouth.

Streams and Rivers: Habitats Partitioned at Different Spatial Scales

Large-scale differences: Source to mouth

The blue line of a river on a map conveniently represents rivers as two-dimensional habitats beginning (usually) in a mountainous region, and ending in a far-off sea (or inland basin). But the physical changes in three dimensions along a river's length have important implications for river inhabitants.

River sources are usually small, and in the case of mountain streams, steep and erosional (Montgomery and Buffington 1997). In temperate environments, small streams tend to be shaded by an interlocking, overhead tree canopy. Such conditions result in cool, well oxygenated streams that are abundantly supplied with a food base of leaves. Fine particles of organic matter are released as the leaves are broken down by biological communities in the streams (*River Continuum Concept*; Figure 1; Vannote *et al.* 1980).

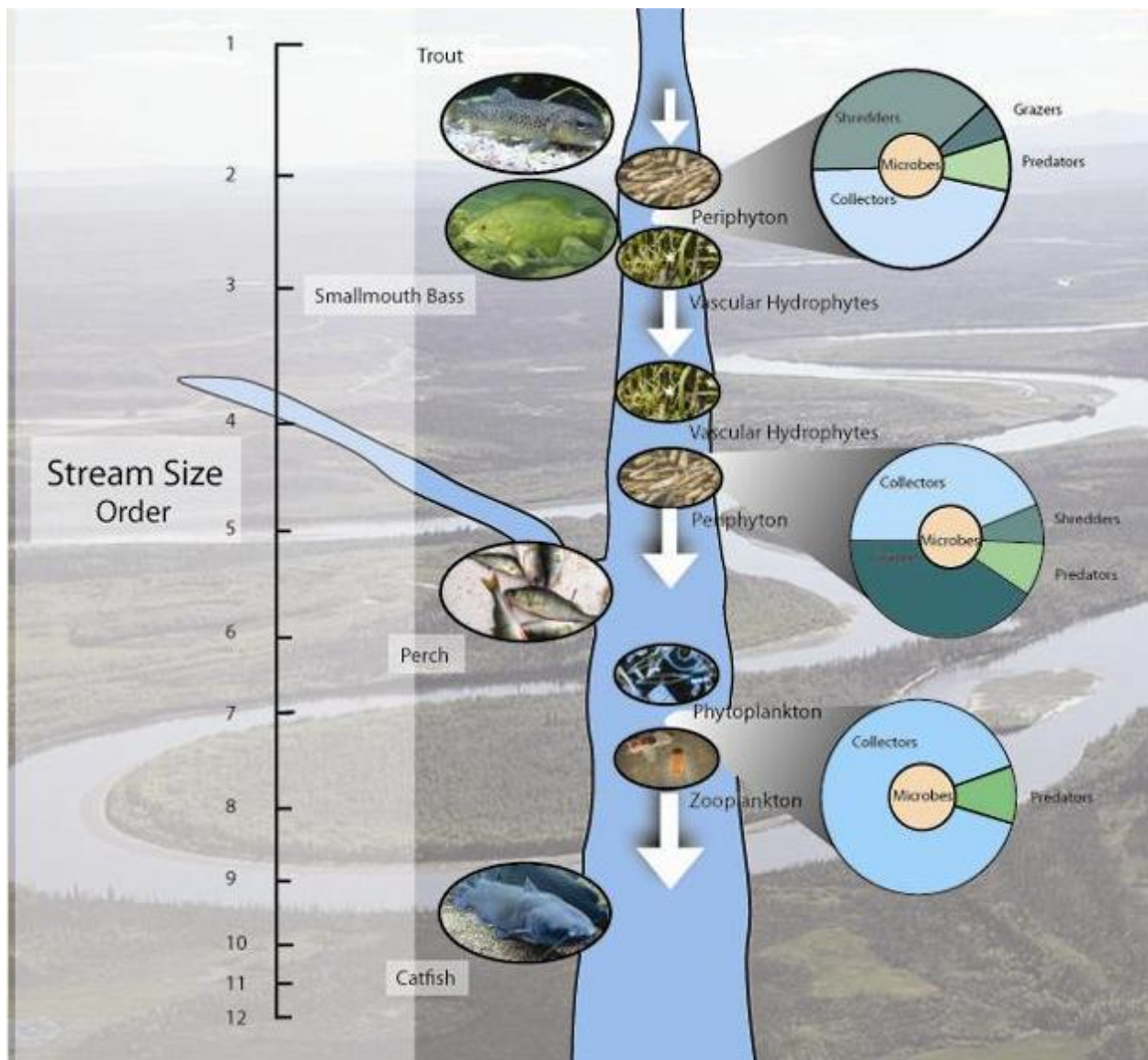


Figure 1: The river continuum concept.

The river continuum concept is a conceptual model that predicts biological community responses to physical changes along the lengths of rivers.

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At some point along their path to the sea, rivers have typically gained enough water and width to preclude interlocking tree canopies. This open-canopy state frequently coincides with somewhat lower gradient landscapes. Streams at this point are warmer, and less abundantly supplied with leaves than was the case upstream. These larger streams remain well oxygenated because air is entrained by turbulent flow in **riffles**. Open canopy, and fairly shallow water, means that light can reach the river **benthos**, increasing in-stream primary productivity.

Very large rivers are usually low gradient and very wide, resulting in negligible influence of **riparian** canopy in terms of shading and leaf-litter input. Water currents keep fine solids in

suspension, reducing light penetration to the benthos. Organic matter in suspension is by far the largest food base in these very large rivers.

Changes in physical habitat and food base from river source to mouth profoundly influence biological communities. Aquatic ecologists classify benthic **macroinvertebrates** into **functional feeding groups**: **shredders** that eat leaves, **collectors** consuming fine particulates, **grazers** that scrape **periphyton** from substrates, and **predators** of animal prey (Cummins & Klug 1979). Smaller temperate streams tend to be co-dominated by shredders primarily consuming leaf litter, and collectors consuming particles (Figure 1). As canopies open in larger streams, grazers become common with increased periphyton production. With less canopy cover in wider streams, shredder abundance is reduced. Collectors utilize particles in streams of all sizes, but they dominate benthic communities in larger streams where suspended organic matter is common. Predators represent a small but important fraction of benthic communities in rivers of all sizes.

The fish zonation concept (Thienemann 1925, cited by Schmutz *et al.* 2000) generalized Western European river habitats based upon a predictable sequence of dominant fish species (Huet 1959). Analogous fish community responses to river slope and size have been found in African, South American, and many North American streams (McGarvey & Hughes 2008). Larger rivers can accommodate larger fish as well as small fish, and so the size range of fish increases as rivers become deeper. River discharge is the volume of water passing a particular location per unit time. The **species-discharge relationship** is analogous to the **species-area relationship**, and describes how fish diversity increases with river size (Figure 2; McGarvey & Milton 2008).

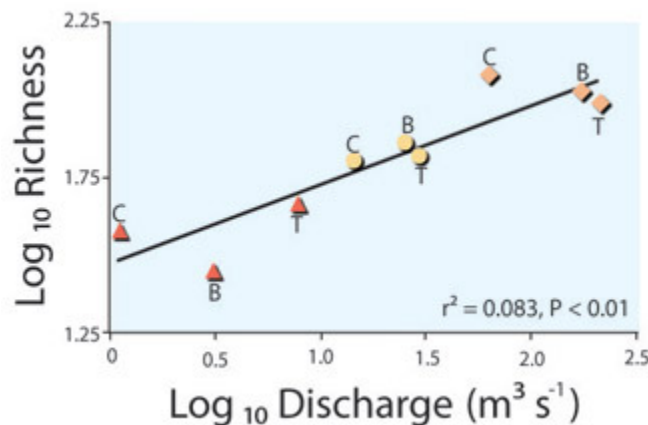


Figure 2: The species discharge relationship.

The species discharge relationship illustrated using samples from the upper (triangles), middle (circles), and lower (diamonds) reaches of three tributaries (B, C, & T) of the Mobile River in southeastern USA.

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The river continuum and fish zonation concepts are idealized models of river systems that provide theoretical frameworks for hypothesis generation and comparisons to particular situations. When rivers pass through lakes, for example, water temperatures, the food base, and downstream communities are all modified (Ward & Stanford 1983). Many stream sources lie above the treeline, have reduced organic matter input, and differ from the predictions of the river

continuum concept. Anthropogenic influences frequently increase particulate matter loading to streams, increasing **filtering collector** component of benthic communities.

Local scale structure: pools, riffles, meanders, and the hyporheic zone

Local stream conditions vary substantially depending on gradient, stream size, and location along a stream continuum. A stream's gradient profile can be generalized as gradually changing from steep to low gradient as we move from high to low elevation and from small to large rivers (Figure 3; Montgomery and Buffington 1997). Steep mountain streams cascade over large pieces of rocky substrate with almost constantly turbulent flow. When a steep stream is confined by valley walls, a series of pools separated by near-vertical steps can form. These **step pools** repeat at a frequency of approximately one to four channel widths.

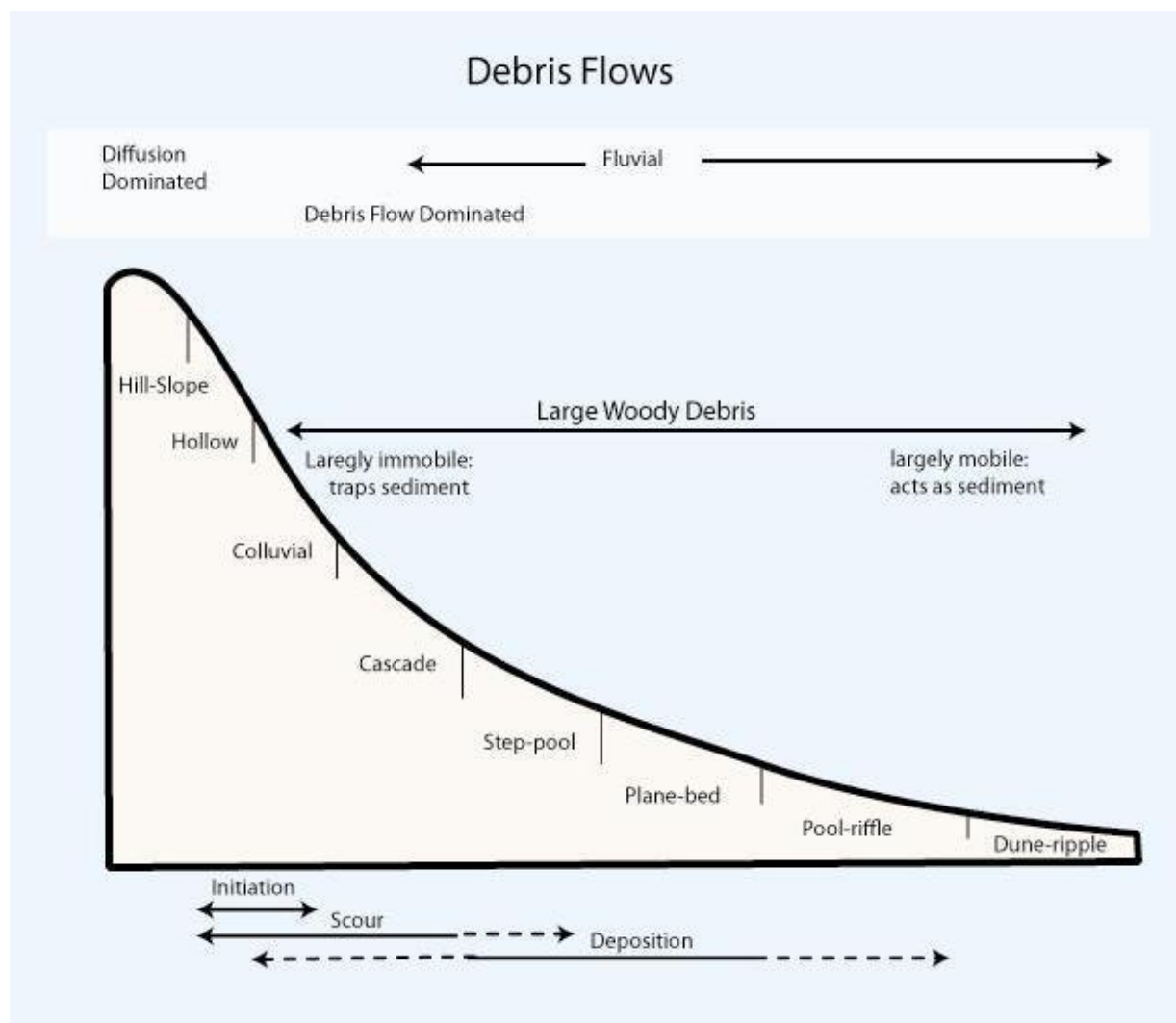


Figure 3: Generalized model of stream gradient and associated river-bed forms.

Generalized model of stream gradient and associated river-bed forms from steep mountain streams through low-gradient rivers.

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In low to moderate-gradient streams with loose rocky substrates, cobbles and boulders are mobilized during high-flow events and deposited across the width of river channels forming high-gradient riffles (Figure 4). Riffles are separated by **pools**, forming riffle-pool sequences recurring about three to five times the width of the river (Hynes 1970; Montgomery and Buffington 1997). During typical base-flow conditions, riffles are erosional habitats with fewer deposited fine particles between substrates. Particulate deposition increases as water velocity slows in pools. Riffle macroinvertebrate communities are typically more diverse than communities in pools. The pattern in fish communities is reversed, with pool fish communities tending to be more diverse than those in riffles (Figure 5; Gelwick 1990, Langeani *et al.* 2005).

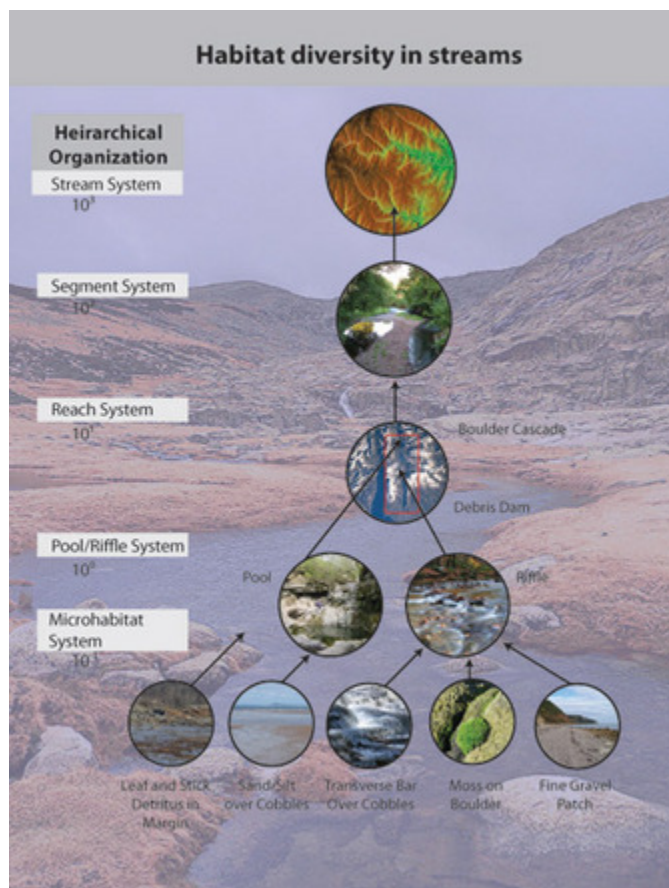


Figure 4: Habitat diversity in streams. Habitat diversity in streams illustrated from large to micro scale.

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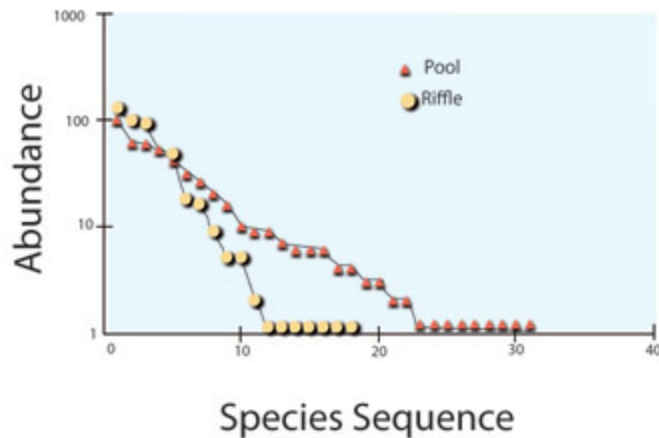


Figure 5: Differences in fish diversity between riffles and pools in rivers in southeastern Brazil.

Species are represented, left to right, from most abundant to least. Pool communities have more species (31 spp) than riffles (18 spp), and are more even, as indicated by the lower slope of the pool plot.

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Larger **alluvial** rivers in their natural state are diverse habitats with side channels, sand and gravel bars, and islands that are formed and reformed on a regular basis (Figure 6; Ward & Tockner 2001). In low gradient flood plains, unconstrained rivers form meanders that shift and move as bed materials are eroded and redeposited. Dramatic changes can occur rapidly during flood events.

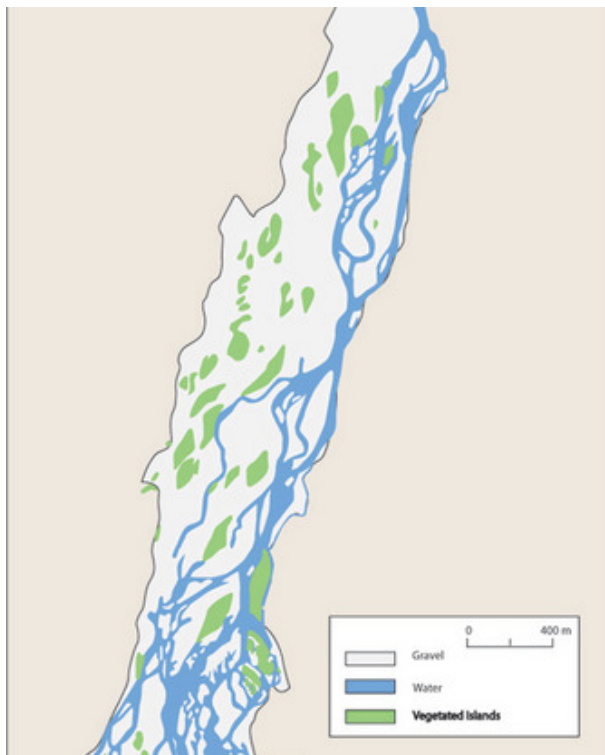


Figure 6: Map of the floodplain of a large low-gradient river.

Map of the floodplain of a large low-gradient river in Italy showing the braided channel, deposited gravel, and vegetated islands. Many, if not most, large rivers have been channelized and contained, such that the natural state shown in this diagram is no longer the norm.

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Streams exchange water, nutrients, and organisms with surrounding **aquifers**. The interstitial, water-filled space beneath river beds, where most active aquifer-river water exchange occurs, is termed the **hyporheic zone**, and is an important habitat for a number of aquatic organisms (Figure 7; Gibert et al. 1994, and references therein). The limits of the hyporheic zone vary, and riverine organisms can be found in groundwater up to 2 km from active stream channels (Stanford & Ward 1988).

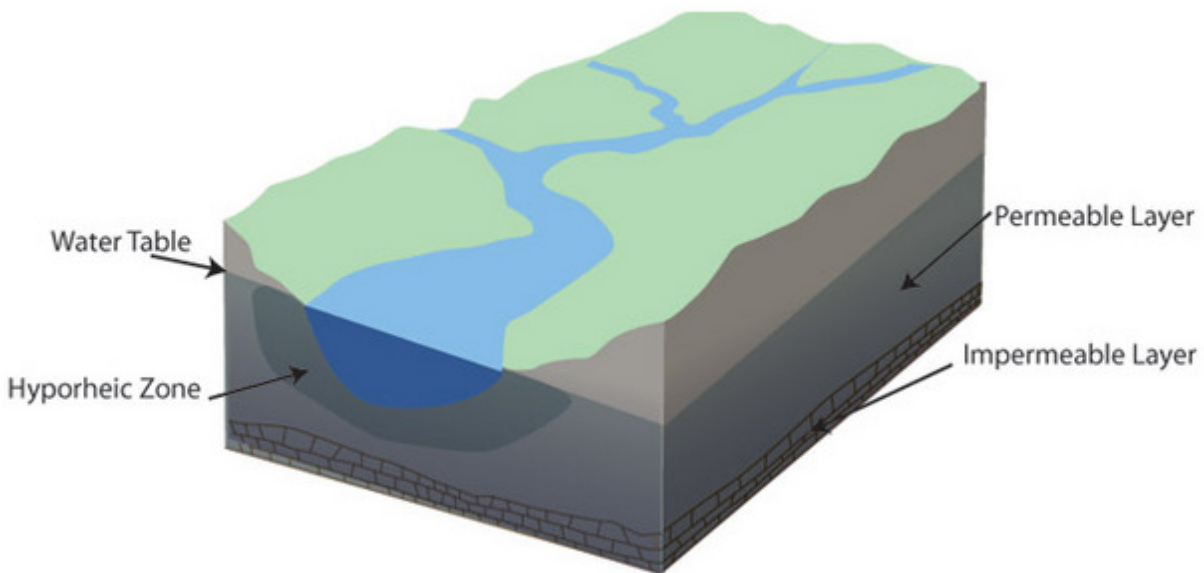


Figure 7: A river's hyporheic zone consists of water in the interstices below a riverbed.

A river's hyporheic zone consists of water in the interstices below a riverbed. This zone is biologically active, and can function as a refuge for organisms during high-water events.

Courtesy of Minnesota Department of Natural Resources.

Gradients in physical characteristics, including flow, depth, substrate characteristics, and light penetration, exist across river channels. These physical differences within a river result in a diverse range of potential niches for aquatic organisms. Because of the heterogeneous nature of riverbeds, the distributions of fish, invertebrates, and algae, tend to form a patchy mosaic that shifts and responds dynamically to high-water events (Townsend 1989). One result of this patchiness is that samples of river organisms are notoriously variable.

Small scale differences: Microhabitats

Organisms distribute themselves at even smaller spatial scales than those described above. The size and texture of river substrates influence invertebrate abundance and species richness (Downes *et al.* 1995). Invertebrate communities respond to different combinations of velocity, depth, and substrate roughness (Brooks *et al.* 2005). As is true in other habitats, the distributions of river organisms are additionally influenced by biological interactions.

Exchange With Surrounding Environments

Rivers exchange water, materials, energy, and nutrients, in a reciprocal manner with the surrounding environment. River water quality, sediment characteristics, and biological communities, all reflect characteristics of the upstream, and even the downstream environment. Conversely, local environments are thermally influenced, sculpted, watered, and nutritionally supplemented, by rivers and streams.

Soil deposition by rivers onto their floodplains has influenced the course of human agriculture, and the distributions of human populations since antiquity. River influence is strongest on the immediately-adjacent habitat called the **riparian zone**. Biological communities in riparian zones are unique, and distinct from those beyond the immediate influence of rivers. In some **biomes** such as deserts and grasslands, river corridors are the most vegetated habitats that exist, and provide essential habitat for a range of organisms. Riparian woods serve as important wildlife migration corridors linking fragmented forests (Lees and Peres 2008).

Upstream migrations of **anadromous** fish species bring marine-derived nutrients to the lotic environment (Wold & Hershey 1999). Fish carcasses increased insect abundance eight-fold in one experiment (Wipfli *et al.* 1998). Aquatic insects in turn transfer nutrients linking food webs between rivers and their riparian zones (Nakano & Murakami 2001). Larval aquatic insects spend weeks, more typically a year, or even longer, in streams before adult emergence. The synchronous insect emergences sought by trout anglers, and indeed by trout, are sometimes large enough to be detected by regional weather radar (Figure 8), and provide vital nutrition for fish, terrestrial invertebrates, birds, and mammals. Terrestrial insects falling into streams constitute important parts of the diets of stream fish, making up as much as 50% of the diet of Dolly Varden Char (*Salvelinus malma*) in one study (Nakano *et al.* 1999).

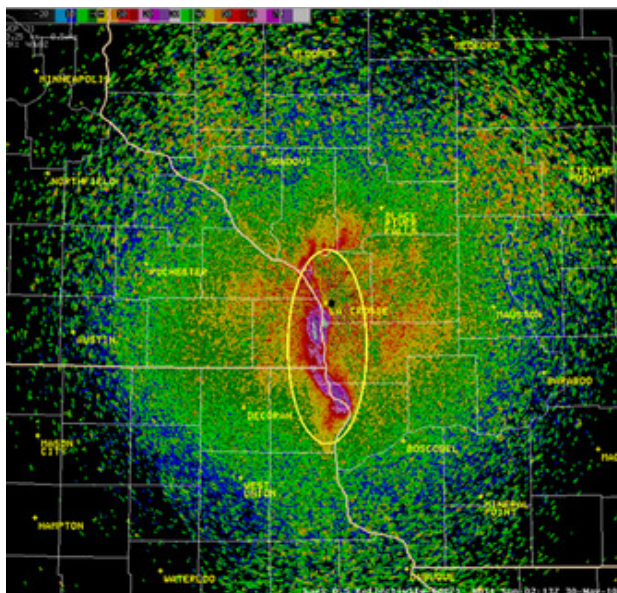


Figure 8: A mayfly mass emergence or ‘hatch’ from the Mississippi river.

A mayfly mass emergence or ‘hatch’ from the Mississippi river captured by the National Weather Service Doppler radar in La Crosse Wisconsin (USA) in May 2010. The adult mayflies in flight are represented by the bright pink, purple, and white.

Courtesy of NOAA Research.

Tree limbs that fall into streams and rivers increase habitat heterogeneity. Submerged woody debris persists for long periods in streams and rivers, with a calculated half-life of ~ 20 years (Hyatt & Naiman 2001). Woody debris can stabilize river beds, modify erosion and deposition, create essential fish habitat, and help form pools that retain organic matter, extending the availability of seasonal food resources. Experimentally manipulated woody debris was shown to increase both macroinvertebrate and fish colonization (Angermeier & Karr 1984).

Stormwater runoff from surrounding landscapes carries particles into streams. The particles include soil as well as plant and animal detritus. Organic particles in the runoff contribute to the food base in stream and river ecosystems.

Disturbance and Community Interactions

Heavy rainfall and snowmelt can greatly magnify the volume of stream water in a relatively short period of time. Rapidly flowing water can carry large quantities of sand and gravel, effectively sand-blasting surfaces, and removing the **periphyton** layer. It is not unusual to see macroinvertebrate abundances reduced by half, or more, following such high-water events. Reviewers of the river literature have generally concluded that disturbance is of greater importance than species interactions in streams (Lake 1990, Resh *et al.* 1988). This conclusion does not imply that community interactions are unimportant, and well-studied examples abound in the scientific literature, but the impacts of disturbance are generally considered to be of greater magnitude. Importantly, river organisms have evolved with a context of natural disturbance, and communities persist in spite of it.

Human Influences

Humans have rapidly introduced a wide array of disturbances to which river organisms have had no previous exposure during their evolution. We have dammed, channelized, diverted, drained, filled, and polluted, streams and rivers. We have removed riparian vegetation, paved extensive portions of river **catchments**, and isolated river systems from their floodplains. Water is transferred among river basins, and river organisms are exchanged among continents. Our influence on rivers has been so pervasive that one research group (Vörösmarty *et al.* 2010) estimated that fully 65% of the river water discharging to our oceans is associated with threatened habitats.

Our influences on river systems alter the nature of rivers and affect all of the processes described above. It is important to note that, because river systems are well studied, environmental engineers have a sound, scientific basis for designing river restoration projects. The general frameworks described above, along with others beyond the scope of this article, provide scientific benchmarks against which to measure the success of restoration efforts.

Summary

The science of life in flowing water is well developed and active. River research is multidisciplinary in nature, and draws from many branches of biology, chemistry, physics, and engineering. Because the vast majority of streams and rivers are in some way managed by human populations, our impacts on these systems can be extensive, as is our potential to improve stream habitat quality. Career opportunities for the next generation of river scientists exist in a wide variety of fields, and these new river scientists will have important influences on the health of rivers in the years to come.

Glossary

Alluvial: Referring to loose inorganic substrates such as sand, gravel, and boulders eroded, transported, and deposited and often sorted by the action of water.

Anadromous: Fish spending most of their life cycle in salt water and migrating to freshwater to reproduce.

Aquifer: Underground water that exists in the interstitial space between substrate particles or porous rock.

Benthos: The community of organisms inhabiting the solid floor, or *benthic zone* of any water body.

Biomes: Large biogeographical regions characterized by a particular community type. They are broadly defined by climatic variables including temperature and precipitation. Examples include desert, rain forest, and tundra.

Catchment: The area that drains to a single stream or river. Frequently referred to as a *river basin*. Synonymous with *watershed* in North American usage.

Collectors: A macroinvertebrate functional feeding group using small organic particles as a primary food source. *Filtering collectors* accumulate this material from the water column. *Gathering collectors* accumulate this material from the benthic zone.

Discharge: The quantity of water passing a certain river or stream location per unit time. Expressed as units of volume per unit time (e.g. cubic meters per second).

Feeding guilds: Organisms categorized by their feeding mode. Examples include nectar feeders, and parasites. See *functional feeding groups*.

Functional feeding groups: Feeding guilds of aquatic macroinvertebrates. These include grazers

(commonly called *scrapers*), shredders, collectors, and predators.

Grazers: Also called scrapers, a macroinvertebrate functional feeding group that consumes attached periphyton as its primary food source

Hyporheic zone: A zone of saturated substrate beneath and spreading laterally from a river bed. It is the zone of active water and organism exchange between the river water and ground water.

Lentic: Referring to standing-water habitats including lakes, ponds, and swamps (contrast with *lotic*).

Lotic: Referring to flowing-water habitats including rivers, springs, and streams (contrast with *lentic*).

Periphyton: The community of primary producers and heterotrophic microorganisms attached to submerged surfaces. In streams this would include algae, cyanobacteria, bacteria, and fungi and their associated extra-cellular secretions. Periphyton serves as the food base utilized by *grazers*.

Pool: An area of low gradient water in a stream. See also *riffle*.

Predators: Organisms whose primary food source is other animals.

Riffle: A high-gradient bar of deposited substrate, usually spanning the width of a stream. Typically found as part of a riffle-pool repeating sequence in streams of medium gradient. Not to be confused with ripple.

Ripple: Small-scale undulations on the surface unconsolidated fine substrates such as silt and sand. These features are shaped by the action of flowing water in low-gradient rivers.

Riparian zone: The area of terrestrial habitat adjacent to and most directly influenced by a river or stream.

River Continuum Concept: A model of longitudinal change in physical habitat, and the biological communities in rivers.

Shredders: A benthic macroinvertebrate functional feeding group that utilizes leafy detritus as their primary food source. Although the leaves are consumed, nutritional value is derived from the attached community as well as the leaves themselves.

Species-area relationship: The frequently-confirmed observation that as one increases the area from which a community sample is taken, one typically samples an increasing number of species.

Species-discharge relationship: An analogous concept to the species-area concept applied to rivers. As river size (as measured by *discharge*) increases, one usually finds more fish species.

Step pools: A series of stream pools separated by areas of high-gradient water flow. These pools can be visualized by analogy to the step surfaces on stairs separated by the stair risers that support those steps.

Watershed: European usage: the boundary between two catchments; water is shed to one stream on one side of this line and in the opposite direction and to a different stream on the other side. North American usage: a synonym of *catchment*.

Strahler Stream Order

United States Geological Survey, 2021

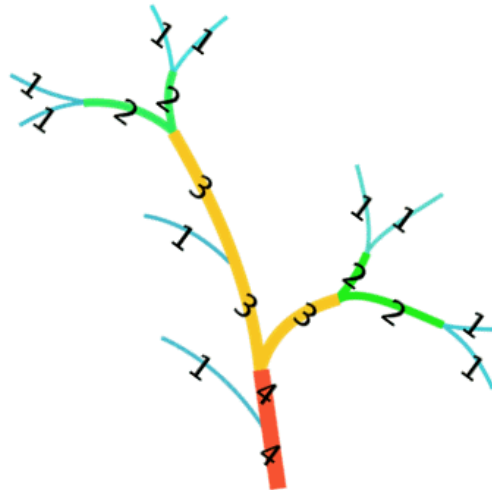
Strahler Stream Order

Stream Order - Stream order (calculated in the NHD using Strahler Stream Order (Strahler, A.N., 1952; Horton, R.E., 1945)) in hydrography deals with the hierarchy of streams from the source (or headwaters) downstream. The NHD is capable of storing stream order information in the NHDFlowlineVAA table. However, since stream order must start at the headwaters of the features, and most subbasins (8-digit hydrologic unit containers) do not contain the headwaters, this attribute is not populated

The headwaters are the first order and downstream segments are defined at confluences (two streams running into each other). The diagram below shows how the downstream numbering of stream order is done. At a confluence, if the two streams are not of the same order then the highest numbered order is maintained on the downstream segment. At a confluence of two streams with the same order, the downstream segment gets the next highest numbered order. Divergences such as braided streams actually maintain the same order all the way through the braid, just like it was a single stream; however, divergences that are not braided streams keep the upstream order number and follow the normal hierarchy further downstream.

Horton, R. E. (1945), "Erosional development of streams and their drainage basins: hydro-physical approach to quantitative morphology", *Geological Society of America Bulletin* 56 (3): 275–370

Strahler, A. N. (1952), "Hypsometric (area-altitude) analysis of erosional topography", *Geological Society of America Bulletin* 63 (11): 1117–1142



2021 NCF-Envirothon Nebraska Aquatic Ecology Study Resources

Key Topic #3: Wetland and Lake Ecology

7. Identify biological communities in a lake and describe their characteristics
8. Classify the different zones in a lake based on physical structure and explain these distinctions.
9. Define a wetland and describe its major characteristics.
10. Classify the different trophic levels in a lake and explain how energy moves from one level to the next.
11. Describe the effects of human impacts, such as increased nutrient loading and erosion, on aquatic ecosystems.

Study Resources

What is a Wetland? – *United States Environmental Protection Agency, 2018* (Page 35 – 36)

Lake Ecology – *Water on the Web, 2004* (Pages 37 – 64)

Aquatic Ecology and the Food Web – *Texas A&M University, 2013* (Pages 65 – 71)

Nebraska Pond Management: Environmental Modifications – *Nebraska Game and Parks Commission, 2013* (Pages 72 – 80)

Study Resources begin on the next page!



What is a Wetland?

United States Environmental Protection Agency, 2018

Definition of a Wetland

Wetlands are areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, including during the growing season. Water saturation (hydrology) largely determines how the soil develops and the types of plant and animal communities living in and on the soil. Wetlands may support both aquatic and terrestrial species. The prolonged presence of water creates conditions that favor the growth of specially adapted plants (hydrophytes) and promote the development of characteristic wetland (hydric) soils.

Categories of Wetlands

Wetlands vary widely because of regional and local differences in soils, topography, climate, hydrology, water chemistry, vegetation and other factors, including human disturbance. Indeed, wetlands are found from the tundra to the tropics and on every continent except Antarctica. **Two general categories of wetlands are recognized: coastal or tidal wetlands and inland or non-tidal wetlands.**

Coastal/Tidal Wetlands

Coastal/tidal wetlands in the United States, as their name suggests, are found along the Atlantic, Pacific, Alaskan and Gulf coasts. They are closely linked to our nation's estuaries where sea water mixes with fresh water to form an environment of varying salinities. The salt water and the fluctuating water levels (due to tidal action) combine to create a rather difficult environment for most plants. Consequently, many shallow coastal areas are unvegetated mud flats or sand flats. Some plants, however, have successfully adapted to this environment. Certain grasses and grasslike plants that adapt to the saline conditions form the tidal salt marshes that are found along the Atlantic, Gulf, and Pacific coasts. Mangrove swamps, with salt-loving shrubs or trees, are common in tropical climates, such as in southern Florida and Puerto Rico. Some tidal freshwater wetlands form beyond the upper edges of tidal salt marshes where the influence of salt water ends.

Inland/Non-tidal Wetlands

Inland/non-tidal wetlands are most common on floodplains along rivers and streams (riparian wetlands), in isolated depressions surrounded by dry land (for example, playas, basins and "potholes"), along the margins of lakes and ponds, and in other low-lying areas where the groundwater intercepts the soil surface or where precipitation sufficiently saturates the soil (vernal pools and bogs). Inland wetlands include marshes and wet meadows dominated by herbaceous plants, swamps dominated by shrubs, and wooded swamps dominated by

trees. Certain types of inland wetlands are common to particular regions of the country. For more information, see [Wetland Classifications and Types](#) for a full list.

Many of these wetlands are seasonal (they are dry one or more seasons every year), and, particularly in the arid and semiarid West, may be wet only periodically. The quantity of water present and the timing of its presence in part determine the functions of a wetland and its role in the environment. Even wetlands that appear dry at times for significant parts of the year -- such as vernal pools-- often provide critical habitat for wildlife adapted to breeding exclusively in these areas.

For more information about wetlands, please visit our [Wetland Factsheet Series](#). *(This is a supplementary resource if you would like to explore further.)*

Lake Ecology

Water on the Web, 2004

Density Stratification

In the spring, immediately after [ice-out](#) in [temperate](#) climates, the [water column](#) is cold and nearly [isothermal](#) with depth. The intense sunlight of spring is absorbed in the water column, which also [heats](#) up as the average daily temperature of the air increases. In the absence of wind, a [temperature profile](#) with depth might be expected to resemble Figure 2 (see the [Light section](#)), decreasing exponentially with depth. However, [density](#), another physical characteristic of water, plays an important role in modifying this pattern.

Water differs from most other compounds because it is less dense as a solid than as a liquid. Consequently ice floats, while water at temperatures just above freezing sinks. As most compounds change from a liquid to a solid, the molecules become more tightly packed and consequently the compound is denser as a solid than as a liquid. Water, in contrast, is most dense at 4°C and becomes less dense at both higher and lower temperatures. The density/temperature relationship of fresh water is shown in Figure 3. Because of this density-temperature relationship, many lakes in temperate climates tend to stratify, that is, they separate into distinct layers.

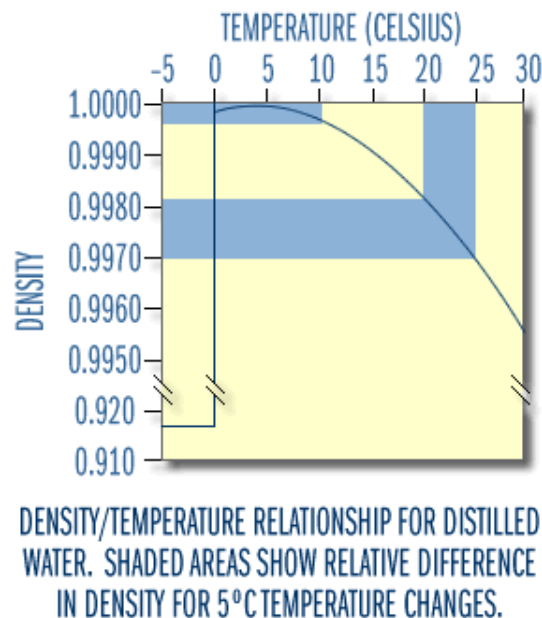


Figure 3

Spring

In lakes of the upper Midwest and at higher elevations, the water near a lake's bottom will usually be at 4°C just before the lake's ice cover melts in the spring. Water above that layer will

be cooler, approaching 0°C just under the ice. As the weather warms, the ice melts. When the temperature (density) of the surface water equals the bottom water, very little wind energy is needed to mix the lake completely. This is called [turnover](#). After this [spring turnover](#), the surface water continues to absorb heat and warms. As the temperature rises, the water becomes lighter than the water below. For a while winds may still mix the lake from bottom to top, but eventually the upper water becomes too warm and too buoyant to mix completely with the denser deeper water. As Figure 3 suggests, the relatively large differences in density at higher temperatures are very effective at preventing mixing. It simply takes too much energy to mix the water any deeper.

It is useful to visualize a more extreme example of [density stratification](#). Imagine a bottle of salad dressing containing vegetable oil and vinegar. The oil is lighter (more buoyant) than the vinegar which is mostly water. When you shake it up you are supplying the energy to overcome the buoyant force, so the two fluids can be uniformly mixed together. However, if allowed to stand undisturbed, the more buoyant (less dense) oil will float to the top and a two-layer system will develop.

In some cases, such as happened at Ice Lake in April, 1998 and 1999, the surface water may warm up rapidly immediately after ice-out, causing the lake to stratify thermally without completely mixing. This prevents atmospheric oxygen from reaching the bottom waters. As a consequence, the entire water column never reaches 100% oxygen [saturation](#). This can be observed for Ice Lake by comparing temperature and oxygen profiles from March 5, 1998 (still frozen), April 18, 1998 (the lake was completely ice-free on April 11, 1998), and April 30, 1998.

Summer

As summer progresses, the temperature (and density) differences between upper and lower water layers become more distinct. Deep lakes generally become physically [stratified](#) into three identifiable layers, known as the [epilimnion](#), [metalimnion](#), and [hypolimnion](#) (Figure 4). The epilimnion is the upper, warm layer, and is typically well mixed. Below the epilimnion is the metalimnion or [thermocline](#) region, a layer of water in which the temperature declines rapidly with depth. The hypolimnion is the bottom layer of colder water, isolated from the epilimnion by the metalimnion. The density change at the metalimnion acts as a physical barrier that prevents mixing of the upper and lower layers for several months during the summer.

The depth of mixing depends in part on the exposure of the lake to wind (its [fetch](#)), but is most closely related to the lake's size. Smaller to moderately-sized lakes (50 to 1000 acres) reasonably may be expected to stratify and be well mixed to a depth of 3–7 meters in north temperate climates. Larger lakes may be well mixed to a depth of 10–15 meters in summer (e.g., Western Lake Superior near Duluth, MN).

Note that although "thermocline" is a term often used synonymously with metalimnion, it is actually the plane or surface of maximum rate of decrease of temperature with respect to depth. Thus, the thermocline is the point of maximum temperature change within the metalimnion.

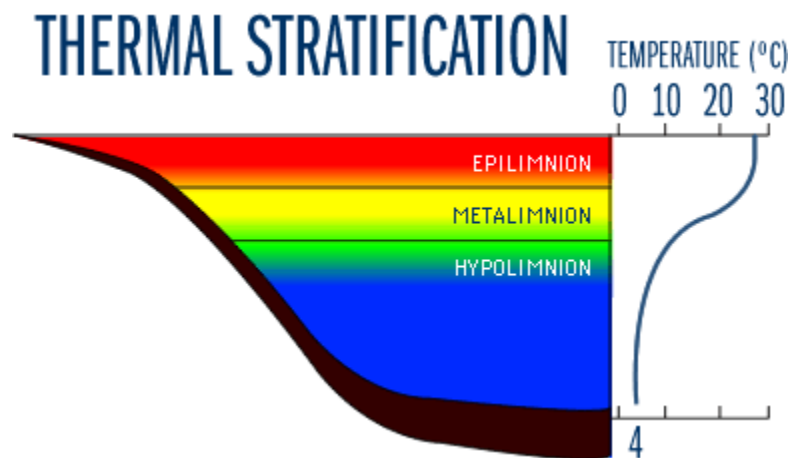


Figure 4

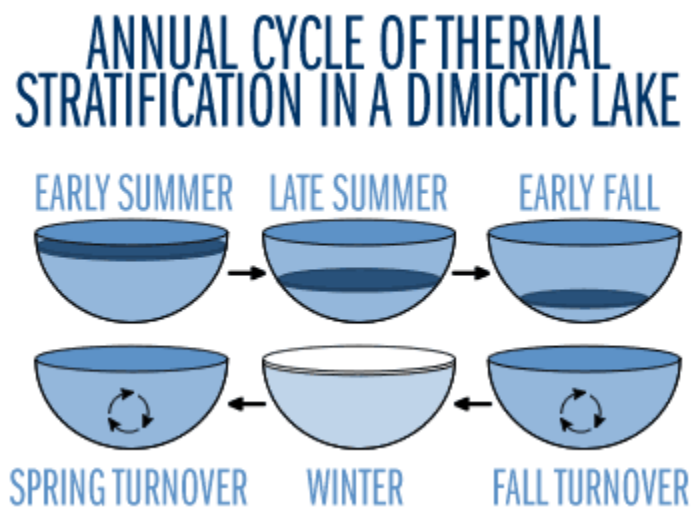


Figure 5

Autumn

As the weather cools during autumn, the epilimnion cools too, reducing the density difference between it and the hypolimnion (Figure 5). As time passes, winds mix the lake to greater depths, and the thermocline gradually deepens. When surface and bottom waters approach the same temperature and density, autumn winds can mix the entire lake; the lake is said to "turn over." As

the atmosphere cools, the surface water continues to cool until it freezes. A less distinct density stratification than that seen in summer develops under the ice during winter. Most of the water column is isothermal at a temperature of 4°C, which is denser than the colder, lighter water just below the ice. In this case the [stratification](#) is much less stable, because the density difference between 0°C and 4°C water is quite small. However, the water column is isolated from wind-induced turbulence by its cap of ice. Therefore, the layering persists throughout the winter.

Here are some videos that demonstrate density stratification. (Our apologies for their quality.)

- [Movie 1](#) - Here's what happens when warmer water (green) enters the surface of a lake in winter. The second addition shows that the warm water is buoyant (less dense) than the cold water and therefore rises.
- [Movie 2](#) - Here's what happens when colder water enters a summer-stratified lake.
- [Movie 3](#) - Same as movie 2 without the dyed green epilimnion.
- [Movie 4](#) - See what happens to the epilimnion (mixed layer) and thermocline during a storm. Did the lake mix?
- [Movie 5](#) - Same as movie 4, but with increased turbulence. See what starts to happen when the class 5 tornado hits.
- [Movie 6](#) - Shows how stream sediment entering a lake or reservoir deposits its load. Why does some material stay in the upper layer and some crash to the bottom?
- [Movie 7](#) - An estuary is a 2-layer system with freshwater overlying salt water. Here we see how freshwater behaves when added to each layer.
- [Movie 8](#) - Same as movie 7, but here we introduce water that is saltier than the upper freshwater layer. Example: Hurricanes can "throw" huge amounts of saltwater into coastal lakes. What happens to this water and what might its impact be?

Overview

This pattern (spring turnover — summer stratification — fall turnover — winter stratification) is typical for [temperate](#) lakes. Lakes with this pattern of two mixing periods are referred to as [dimictic](#). Many shallow lakes, however, do not stratify in the summer, or stratify for short periods only, throughout the summer. Lakes that stratify and destratify numerous times within a summer are known as [polymictic](#) lakes. Both polymictic and dimictic lakes are common in Minnesota.

Since installing the RUSS unit in Ice Lake we have made an interesting observation. Spring turnover is incomplete. There was not enough mixing in spring, 1998 or 1999 to completely re-aerate the entire water column to 100% saturation. On the other hand, Lake Independence, a lake of comparable depth (15-18 meters) but much larger in size (more fetch) and less sheltered from the wind, mixed completely. We suspect that most aquatic scientists would not have expected to see Ice Lake's bottom water, nearly saturated with [oxygen](#) in fall, 1998, to be [anoxic](#) by mid-winter and then persist in this state until the following fall. Once stratified thermally in summer, even the barrage of severe thunderstorms that occurred near Ice Lake in summer, 1999,

lacked the energy to dramatically decrease the thermocline or increase the oxygen content of the hypolimnion. [Heat and Oxygen budget section of Ice Lake](#).

It was cold and windy enough during fall, 1998 for Ice Lake to mix thoroughly, bringing oxygen to the bottom waters (to about 100% saturation). This is likely typical for Ice Lake during most autumns, although it is possible for a cold, calm period to allow the lake surface to freeze before the water column has been fully exposed to the atmosphere and re-charged with oxygen.

Visit the data files under [each lake page](#) or review the entire data set using the [Data Visualization Tools](#).

STRATIFICATION OF A MEROMICTIC LAKE

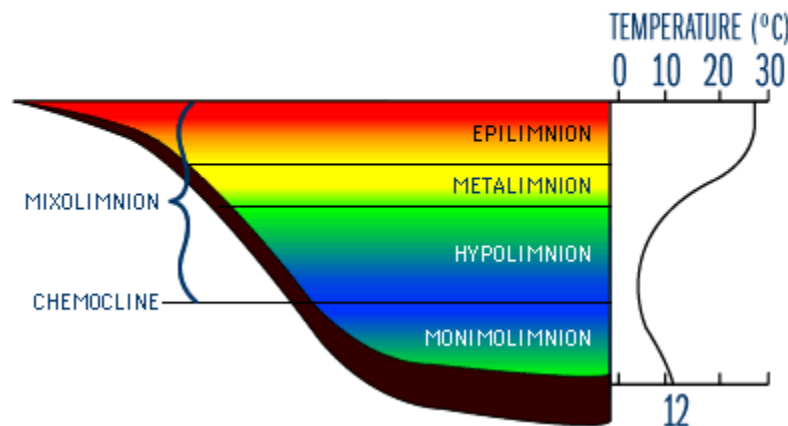


Figure 6

The West Upper Lake Station of Lake Minnetonka, Lake Independence and thousands of other Upper Midwestern lakes that are relatively deep (>10 meters) and reasonably large (>100-200 acres or 40-80 ha) are probably dimictic, leading to complete re-oxygenation of the water column for at least some period of time. Ice Lake, though small (41 acres or 16.6ha), is sheltered and deep (16 m) for its size. Lakes that have formed in former open pit mines in Northeastern Minnesota are unusually deep for their size. Lakes with these characteristics probably only mix completely once a year in the fall for a brief period before freezing. Some of the deeper mine pit lakes (>75 meters deep) probably never mix completely to the bottom, although data are sparse. Much less common are lakes that circulate incompletely resulting in a layer of bottom water that remains stagnant. To distinguish them from the [holomictic](#) (mixing from top to bottom) lakes, these partially mixing lakes are referred to as [meromictic](#). They mix partially, in the sense that they may have extensive mixing periods which go quite deeply into the hypolimnion, but they do not turn over completely, and a layer of bottom water remains stagnant and anoxic for years at a time. The non-mixing bottom layer is known as the [monimolimnion](#) and is separated from the [mixolimnion](#) (the zone that mixes completely at least once a year) by

the [chemocline](#) (Figure 6). The stagnant, and typically [anaerobic](#), monimolimnion has a high concentration of dissolved solids compared to the mixolimnion. In general, meromictic lakes have large [relative depths](#). These lakes are typically small and sheltered from the wind by the morphology of their [basin](#). In this case, the density differences caused by temperature are smaller than density differences due to the high dissolved solids (salts) concentration of the monimolimnion. Large lakes that rarely freeze over are also typically monomictic, mixing throughout the fall, winter and spring and stratifying in the summer.

To visualize this effect, try dissolving several tablespoons of table salt (NaCl) in hot water. Add a few drops of food coloring and then fill a mayonnaise jar half-full. Now, very gently add cool tap water with a small measuring cup to fill the glass. Set up a second jar half full with clear, cool water and then add the colored hot water to fill the glass - but don't add the salt. Compare the stability of the density stratification in the two systems by gently shaking or stirring the water columns.

Table 2

MIXING REGIME	LAKES	MAX DEPTH (m)	AREA (acres/hectares)
DIMICTIC (2mixes/yr)	Lake Minnetonka (Minneapolis, MN)	34	14,004 acres (5,670 ha)
	Grindstone Lake (Sandstone, MN)	46	500 acres (200 ha)
	Lake Independence (Minneapolis, MN)	18	850 acres (344 ha)
	Pike Lake (Duluth, MN)	18	500 acres (200 ha)
MONOMICTIC (1mix/yr – mixed all winter and spring)	Lake Erie	70	6.4 x 10 ⁶ acres (2.6 x 10 ⁶ ha)
	Lake Huron	228	14.8 x 10 ⁶ acres (6.0 x 10 ⁶ ha)
	Ice Lake* (Grand Rapids, MN)	16	41 acres (16.6 ha)
	Lake Michigan	281	14.4 x 10 ⁶ acres (5.8 x 10 ⁶ ha)
	Lake Ontario	244	4.9 x 10 ⁶ acres (2.0 x 10 ⁶ ha)
	Lake Superior	300	20.3 x 10 ⁶ acres (8.2 x 10 ⁶ ha)
	Lake Tahoe (CA/NV)	499	123,253 acres (49,900 ha)
	Lake Mead (NV – largest US reservoir)	180	163,320 acres (66,096 ha)
POLYMICTIC (many mixes/yr)	Shallow lakes & ponds	< 4	wide range
	Mille Lacs Lake , MN	13	132,510 acres (53,648 ha)

	St. Louis River and Duluth-Superior Harbor	1-8	11,993 acres (4,856 ha)
MEROMICTIC (never totally mixed because of stagnant bottom layer)	Miners Pit Lake (Ely, MN)	48	138 acres (56 ha)
	Pennington Pit Lake , (Crosby, MN)	79	57 acres (23 ha)
	Brownie Lake (Minneapolis, MN)	15	18 acres (7.3 ha)
	Deming Lake (Itasca State Park, MN)	14	12.3 acres (5.0 ha)
	Big Soda Lake (Fallon, NV)	60	400 acres (160 ha)
* variable from year to year			

For additional information, Learn about ARCHIMEDES's principle at [EXPLORATORIUM](#) and a shockwave demonstration of [density and water displacement](#)

The Watershed

The [watershed](#), also called the drainage [basin](#), is all of the land and water areas that drain toward a particular river or lake. Thus, a watershed is defined in terms of the selected lake (or river). There can be subwatersheds within watersheds. For example, a [tributary](#) to a lake has its own watershed, which is part of the larger total drainage area to the lake.

A lake is a reflection of its watershed. More specifically, a lake reflects the watershed's size, [topography](#), geology, [landuse](#), soil fertility and erodibility, and vegetation. The impact of the watershed is evident in the relation of [nutrient loading](#) to the watershed:lake surface area ratio (Figure 7). See also the section on [conductivity](#).

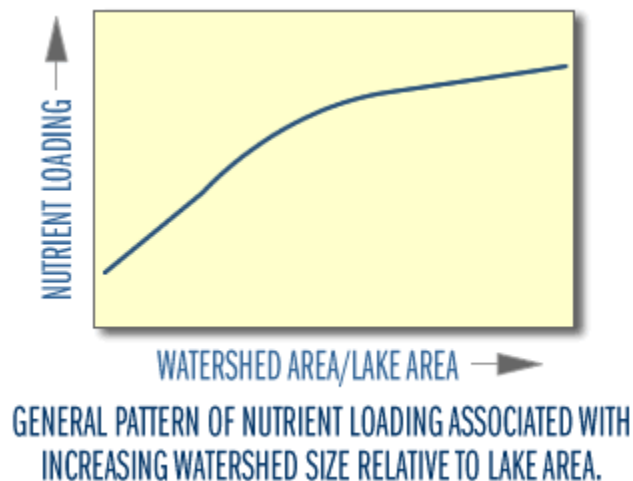


Figure 7

Typically, water quality decreases with an increasing ratio of [watershed area](#) to lake area. This is obvious when one considers that as the watershed to lake area increases there are additional sources (and volumes) of runoff to the lake. In larger watersheds, there is also a greater opportunity for water from precipitation to contact the soil and [leach](#) minerals before discharging into the lake. Lakes with very small watersheds that are maintained primarily by groundwater flow are known as [seepage lakes](#). In contrast, lakes fed primarily by inflowing streams or rivers are known as [drainage lakes](#). In keeping with the watershed:lake area relationship, seepage lakes tend to have good water quality compared with drainage lakes. However, lakes are often more susceptible to acidification from [acid rain](#) because of their low [buffering capacity](#).

STORMWATER DISCHARGES FROM VARIOUS LAND COVERS

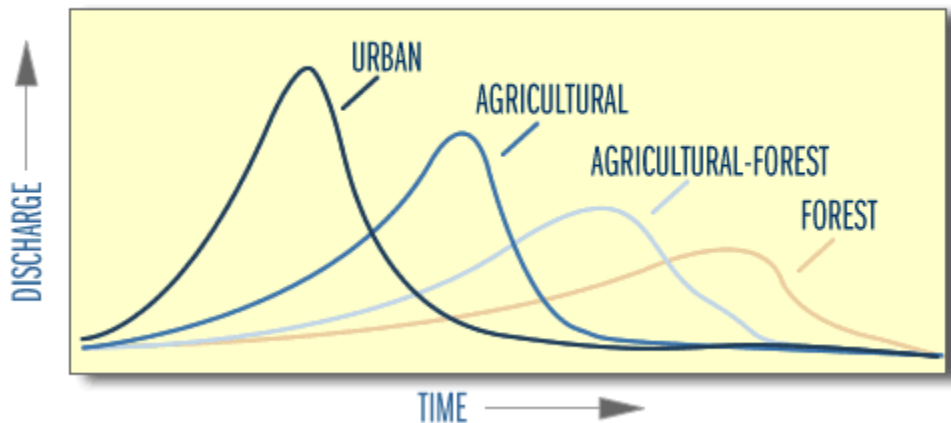


Figure 8

Landuse has an important impact on the quality and quantity of water entering a lake. As Figure 8 shows, the [stormwater discharge](#) to a lake differs greatly among landuses. In urban areas, the high proportion of [impervious surfaces](#) prevents absorbance of rainwater into the soil and increases the rate of surface water flow to the lake. The high [flushing rates](#) from urban areas can increase erosion of stream banks and provide sufficient force to carry large particles (i.e., soil) to the lake. Thus, water quantity affects water quality.

Additionally, as water flows over roads, parking lots and rooftops, it accumulates nutrients and contaminants in both dissolved and particulate form.

Table 3. Phosphorus export coefficients (from Reckhow and Simpson, 1980).			
	Phosphorus (kg/km²yr)		
	HIGH	MID	LOW
Urban	500	80-300	50
Rural/Agriculture	300	40-170	10
Forest	45	14-30	2
Precipitation	60	20-50	15

Table 3 gives representative values of [export rates](#) of [phosphorus](#) from various landuses and other sources. Phosphorus is particularly important because its availability often controls the amount of algae and the overall [productivity](#) of a lake. These values are in units of kg/km²/yr (mass of phosphorus per unit area per year). Not included here, but also important, is the influence of soil type and slope. Finer particles and steeper slopes mean higher [export rates](#). To clarify the relative landuse impacts, we can compare annual loads from 10 hectare (24 acre) plots of the selected landuses using the high export coefficients in Table 3.

Forest	4.5 kg phosphorus
Rural/Agriculture	30.0 kg phosphorus
Urban	50.0 kg phosphorus

One can see that, all other things being equal, converting a forest into a city can increase the phosphorus export to a lake more than ten times. Another way to look at these numbers is that almost seven years of [phosphorus](#) loading from a forested area can be deposited within one year by mixed agriculture areas and almost eleven years of phosphorus loading from a forested area can be deposited within a year from urbanized areas. A greater [loading rate](#) puts a greater strain on the system to assimilate the nutrients.

Dissolved Oxygen

Biological activity peaks during the spring and summer when photosynthetic activity is driven by high solar [radiation](#). Furthermore, during the summer most lakes in [temperate](#) climates are [stratified](#). The combination of [thermal stratification](#) and biological activity causes characteristic patterns in water chemistry. Figure 9 shows the typical seasonal changes in [dissolved oxygen](#) (DO) and temperature. The top scale in each graph is [oxygen](#) levels in mg O₂/L. The bottom scale is temperature in °C. In the spring and fall, both [oligotrophic](#) and [eutrophic](#) lakes tend to have uniform, well-mixed conditions throughout the [water column](#). During summer [stratification](#), the conditions in each layer diverge.

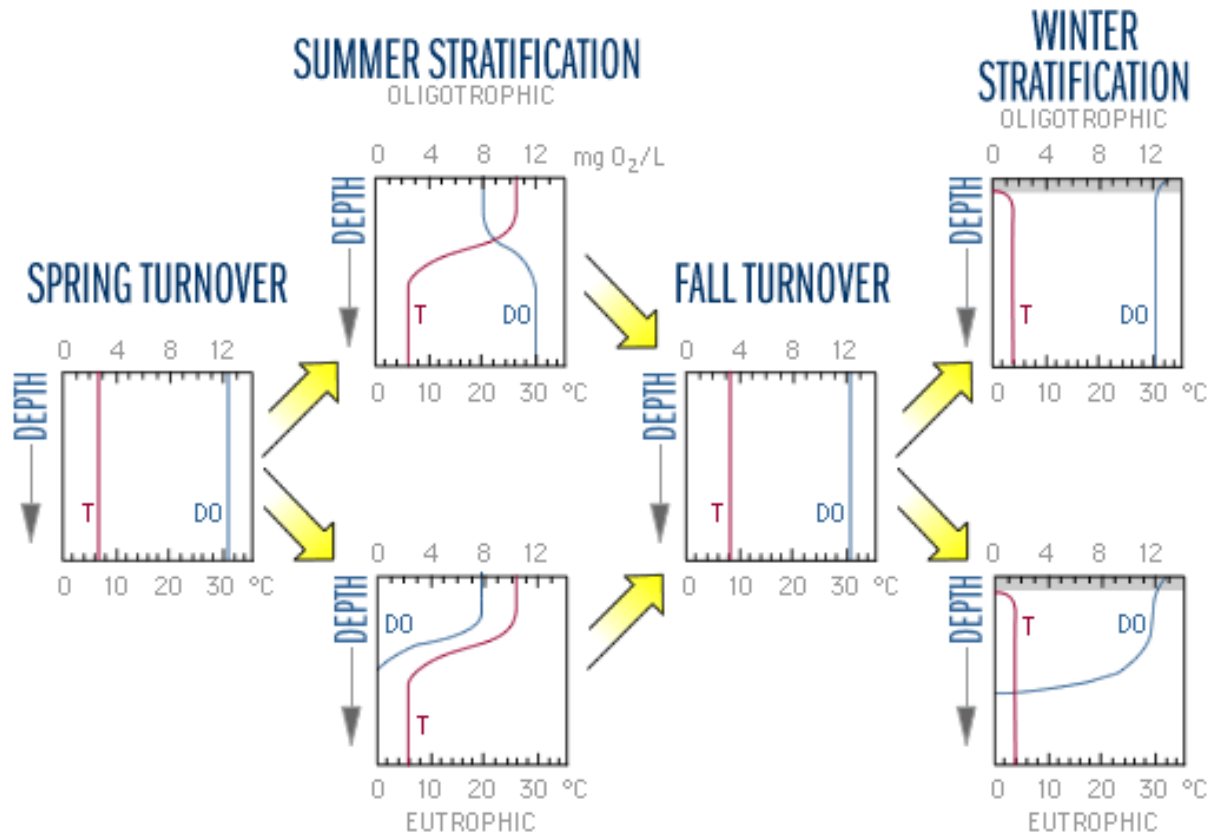


Figure 9 - (adapted from Figure 8-1 in Wetzel, R.G. 1975. *Limnology*. W.B. Saunders Company)

The **DO** concentration in the **epilimnion** remains high throughout the summer because of **photosynthesis** and **diffusion** from the atmosphere. However, conditions in the **hypolimnion** vary with **trophic** status. In eutrophic (more productive) lakes, hypolimnetic DO declines during the summer because it is cut-off from all sources of oxygen, while organisms continue to respire and consume oxygen. The bottom layer of the lake and even the entire hypolimnion may eventually become **anoxic**, that is, totally devoid of **oxygen**. In oligotrophic lakes, low algal **biomass** allows deeper light penetration and less **decomposition**. Algae are able to grow relatively deeper in the **water column** and less oxygen is consumed by decomposition. The DO concentrations may therefore increase with depth below the **thermocline** where colder water is "carrying" higher DO leftover from spring mixing (recall that oxygen is more soluble in colder water). In extremely deep, unproductive lakes such as Crater Lake, OR, Lake Tahoe, CA/NV, and Lake Superior, DO may persist at high concentrations, near 100% saturation, throughout the water column all year. These differences between eutrophic and oligotrophic lakes tend to disappear with fall **turnover** (Figure 9).

In the winter, oligotrophic lakes generally have uniform conditions. Ice-covered eutrophic lakes, however, may develop a winter stratification of dissolved oxygen. If there is little or no snow cover to block sunlight, **phytoplankton** and some **macrophytes** may continue to photosynthesize, resulting in a small increase in DO just below the ice. But as microorganisms continue to decompose material in the lower water column and in the sediments, they consume oxygen, and the DO is depleted. No oxygen input from the air occurs because of the ice cover, and, if snow covers the ice, it becomes too dark for photosynthesis. This condition can cause

high fish mortality during the winter, known as "winter kill." Low DO in the water overlying the sediments can exacerbate water quality deterioration, because when the DO level drops below 1 mg O₂/L chemical processes at the sediment-water interface frequently cause release of [phosphorus](#) from the sediments into the water. When a lake mixes in the spring, this new phosphorus and ammonium that has built up in the bottom water fuels increased algal growth.

Nutrients

Aquatic organisms influence (and are influenced by) the chemistry of the surrounding environment. For example, [phytoplankton](#) extract nutrients from the water and [zooplankton](#) feed on phytoplankton. Nutrients are redistributed from the upper water to the lake bottom as the dead plankton gradually sink to lower depths and decompose. The redistribution is partially offset by the active vertical migration of the plankton. In contrast to DO, essential nutrients such as the [bioavailable](#) forms of [phosphorus](#) and nitrogen (dissolved phosphate, nitrate, and ammonium) typically increase in the spring from snowmelt runoff and from the mixing of accumulated nutrients from the bottom during [spring turnover](#). Concentrations typically decrease in the [epilimnion](#) during summer [stratification](#) as nutrients are taken up by algae and eventually transported to the [hypolimnion](#) when the algae die and settle out. During this period, any "new" input of nutrients into the upper water may trigger a "bloom" of algae. Such inputs may be from upstream tributaries after rainstorms, from die-offs of aquatic plants, from pulses of urban stormwater, direct runoff of lawn fertilizer, or from leaky lakeshore septic systems. In the absence of rain or snowmelt, an injection of nutrients may occur simply from high winds that mix a portion of the nutrient-enriched upper waters of the hypolimnion into the epilimnion. In less productive systems, such as those in Northeastern Minnesota, significant amounts of available nitrogen may be deposited during rainfall or snowfall events ([wet deposition](#)) and during the less obvious deposition of aerosols and dust particles ([dry deposition](#)). For instance, Lake Superior has been enriched by as much as 300 µg/L during this century, presumably due to air pollution. Nitrogen and phosphorus in dry fallout and wet precipitation may also come from dust, fine soil particles, and fertilizer from agricultural fields.

Biological

Lake Zones

A typical lake has distinct zones of biological communities linked to the physical structure of the lake (Figure 10). The [littoral](#) zone is the near shore area where sunlight penetrates all the way to the sediment and allows aquatic plants ([macrophytes](#)) to grow. Light levels of about 1% or less of surface values usually define this depth. The 1% light level also defines the [euphotic zone](#) of the lake, which is the layer from the surface down to the depth where light levels become too low for [photosynthesizers](#). In most lakes, the sunlit euphotic zone occurs within the [epilimnion](#).

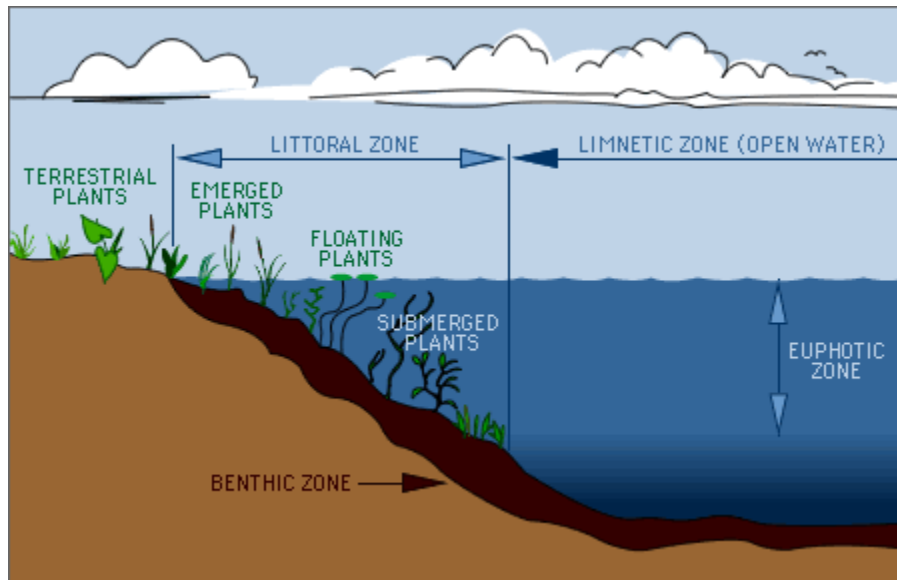


Figure 10

However, in unusually transparent lakes, [photosynthesis](#) may occur well below the [thermocline](#) into the perennially cold [hypolimnion](#). For example, in western Lake Superior near Duluth, MN, summertime algal photosynthesis and growth can persist to depths of at least 25 meters, while the mixed layer, or [epilimnion](#), only extends down to about 10 meters. Ultra-[oligotrophic](#) Lake Tahoe, CA/NV, is so transparent that algal growth historically extended to over 100 meters, though its mixed layer only extends to about 10 meters in summer. Unfortunately, inadequate management of the Lake Tahoe [basin](#) since about 1960 has led to a significant loss of transparency due to increased algal growth and increased sediment inputs from stream and [shoreline](#) erosion.

The higher plants in the littoral zone, in addition to being a food source and a [substrate](#) for algae and invertebrates, provide a habitat for fish and other organisms that is very different from the open water environment.

The [limnetic zone](#) is the open water area where light does not generally penetrate all the way to the bottom. The bottom sediment, known as the [benthic zone](#), has a surface layer abundant with organisms. This upper layer of sediments may be mixed by the activity of the [benthic](#) organisms that live there, often to a depth of 2-5 cm (several inches) in rich [organic](#) sediments. Most of the organisms in the [benthic zone](#) are invertebrates, such as [Dipteran](#) insect larvae (midges, mosquitoes, black flies, etc.) or small crustaceans. The [productivity](#) of this zone largely depends upon the organic content of the sediment, the amount of physical structure, and in some cases upon the rate of fish predation. Sandy substrates contain relatively little organic matter (food) for organisms and poor protection from predatory fish. Higher plant growth is typically sparse in sandy sediment, because the sand is unstable and nutrient deficient. A rocky bottom has a high diversity of potential habitats offering protection (refuge) from predators, substrate for attached [algae](#) ([periphyton](#) on rocks), and pockets of organic "ooze" (food). A flat mucky bottom offers abundant food for benthic organisms but is less protected and may have a lower diversity of structural habitats, unless it is colonized by higher plants.

Lake Organisms

THOSE THAT GO WHERE THEY CHOOSE

FISH

AMPHIBIANS TURTLES

LARGER ZOOPLANKTON AND INSECTS

THOSE THAT GO WHERE THE WATER TAKES THEM

LIVING THINGS = PLANKTON

animals - zooplankton
algae - phytoplankton
bacteria - bacterioplankton

DEAD STUFF = DETRITUS

internal - produced within lake
external - washed in from watershed

THOSE THAT LIVE ON THE LAKE BOTTOM

BENTHOS = ANIMALS

aquatic insects
molluscs - clams, snails
other invertebrates -
worms, crayfish

PLANTS

higher plants -
macrophytes
attached algae -
periphyton

BACTERIA & FUNGI

sewage sludge
aufwuchs - mixture
of algae, fungi
and bacteria

The Food Web

The biological communities within lakes may be organized conceptually into food chains and food webs to help us understand how the ecosystem functions (Figures 12 and 13). The simplest illustration of the organization of the organisms within an ecosystem is the ecological pyramid (Figure 14). The broad base of primary producers supports overlying levels of herbivores (zooplankton), planktivores and much smaller numbers of carnivores (predators). These individual trophic levels may be idealized as a food chain, but in fact many organisms are omnivorous and not necessarily characterized by a particular level. Further, consumers in particular often shift levels throughout their life cycle. For example, a larval fish may initially eat fine particulate material that includes algae, bacteria and detritus. Then it may switch and graze on larger zooplankton and ultimately end up feeding on so called "forage fish" or even young game fish (i.e., top predators) when it reaches maturity (Figure 13).

TYPICAL FOOD CHAIN

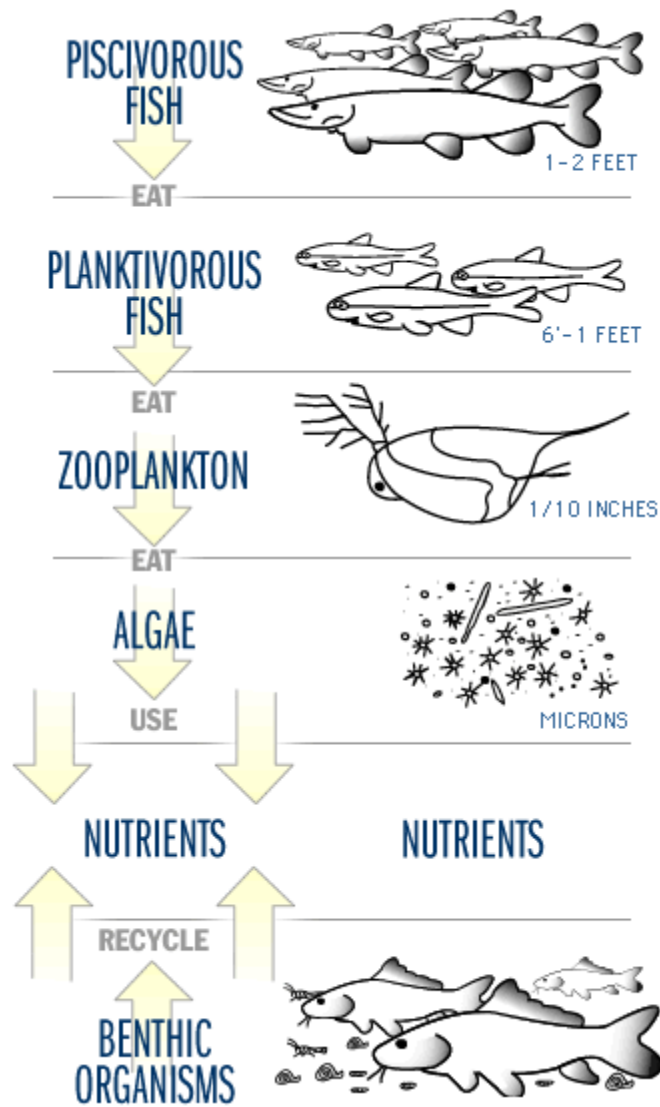


Figure 12

FOOD WEB FOR LAKE MEAD, NV

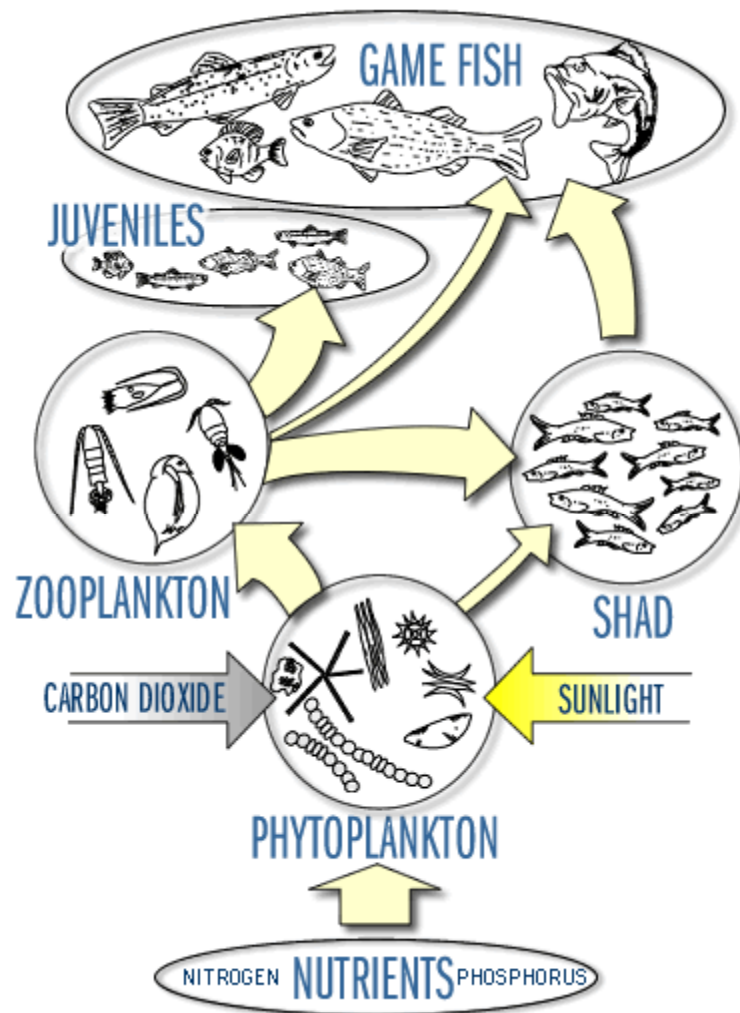


Figure 13

THE ECOLOGICAL PYRAMID

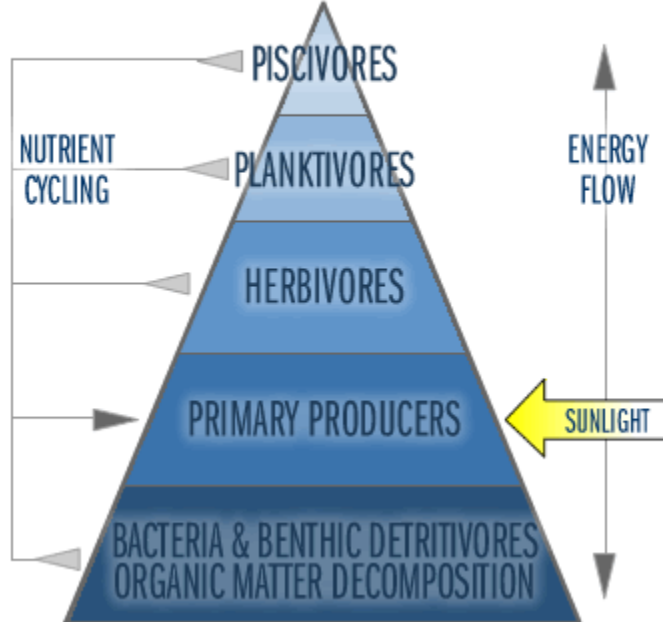


Figure 14

Food webs may be described in terms of both energy and nutrient (carbon, nitrogen or **phosphorus**) flows (Figure 15). Although the process typically begins with sunlight-driven **photosynthesis** by algae and plants, balanced nutrition is also required to sustain life. For example, we cannot live strictly on sugar, despite its high caloric content, irrespective of what our kids may argue.

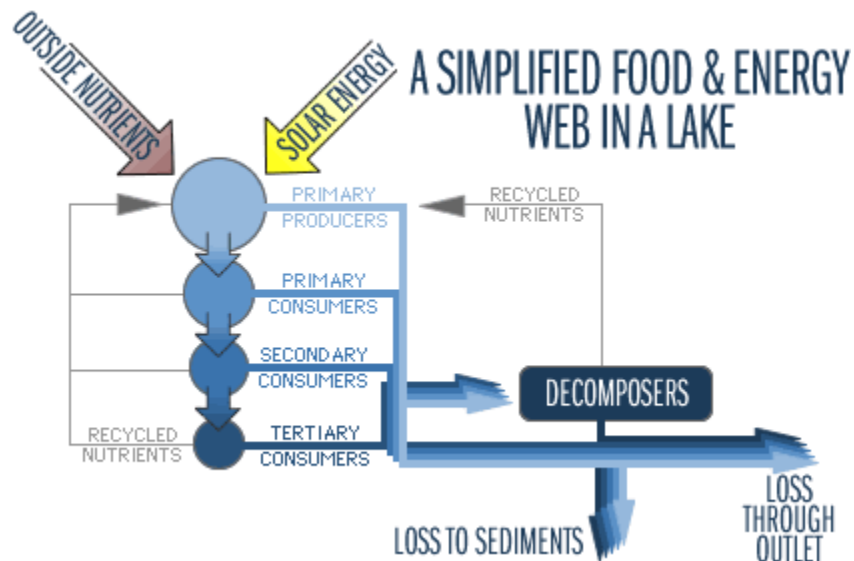


Figure 15

There are two basic life-sustaining processes in lakes, just as on land; [photosynthesis](#) and [respiration](#). Green plants capture energy from sunlight to convert nonliving, [inorganic](#) chemicals ([carbon dioxide](#), water, and mineral compounds) into living, [organic](#) plant tissue. Lake [photosynthesizers](#) include algae and [macrophytes](#). Together, they are the primary producers, because they create the organic material required by most other organisms for nutrients and energy. Oxygen, the waste product of photosynthesis, adds to the [oxygen](#) supplied to the lake by the atmosphere. In water layers where photosynthetic rates are very high, such as during an algal bloom, the water may become supersaturated. That is, the oxygen content may exceed 100% of [saturation](#) with respect to the amount the water could hold if it was allowed to equilibrate with the atmosphere. This saturation value, in turn, depends on the temperature of the water. Colder water can hold more O₂ than warmer water. During periods of [stratification](#), the only potential source of O₂ to the deeper zones of the lake is photosynthesis. This occurs only if light penetrates below the [thermocline](#). In lakes where light does not penetrate below the [thermocline](#), there is no internal source of oxygen to the deeper waters.

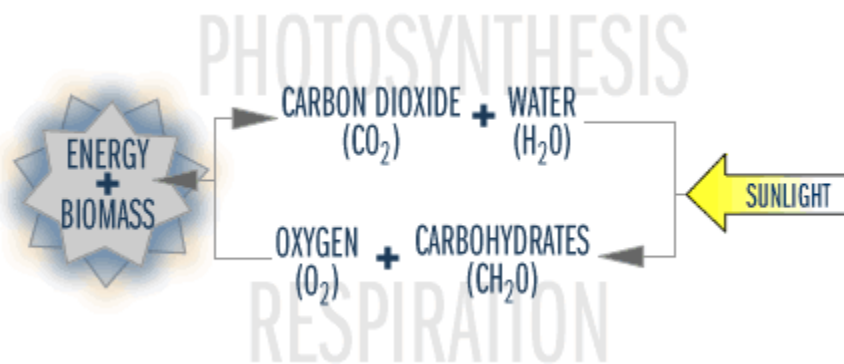


Figure 16

Besides light, algae and higher plants need oxygen, [carbon dioxide](#) (CO₂), and mineral nutrients to survive and grow. Except for a very few species of blue green algae, most are unable to survive in [anoxic](#) (no O₂) water. CO₂ is virtually always available and comes from the [weathering](#) of carbonate rocks, such as limestone, in the watershed, [diffusion](#) from the atmosphere (very important in [softwater](#), [acid rain](#) sensitive lakes), and from the respiration of organic matter by all of the organisms in the lake (see below). Dissolved mineral nutrients are absorbed from the water by algae and from the water and the sediments by higher plants.

Typically, the most important nutrients are phosphorus and nitrogen, because they are present in very low concentrations unless there are sources of pollution (see [trophic state](#) section) and are typically low enough to limit the growth of algae. Other minerals essential to life, such as the major ions (calcium, magnesium, sodium, and potassium) and certain trace metals (iron, cobalt, molybdenum, manganese, copper, boron, and zinc), are usually present at sufficient concentrations. Silicon is required by [diatoms](#) and a few other groups of algae and is usually, though not always, present at sufficient levels. Another mineral required by all living things, sulfur (in the form of sulfate), is typically not deficient in lakes.

The whole interaction of photosynthesis and respiration by plants, animals, and microorganisms represents the food web. Food webs are usually very complex and, in any one lake ecosystem,

hundreds of different species can be involved. Because the available energy decreases at each trophic level, a large food base of primary producers (mostly plants) is necessary to support relatively few large fish.

These plants may die and decompose or be eaten by [primary consumers](#) – the second trophic level. This link in the food chain typically involves zooplankton grazing on algae but also includes larval fish eating zooplankton and a variety of invertebrates that eat attached algae ([periphyton](#)) and higher plants. Other animals, such as small fish, [secondary consumers](#) (third trophic level) eat the primary consumers and thus are considered secondary consumers. Still larger consumers such as large fish, ospreys, and people are [tertiary consumers](#) (fourth trophic level). Thus, energy and nutrients originating from the photosynthetic production of [biomass](#) and energy cascade through the food web (Figure 15). There is some recycling of nutrients back up to the top of the cascade. Respiration, the oxidation of organic material, releases the energy that was originally captured from sunlight by photosynthesis. Both plants and animals respire to sustain their lives, and in doing so, consume oxygen. Microorganisms (bacteria and fungi) consume a large fraction of available oxygen in the [decomposition](#) of excreted and dead organic material.

Decomposers are sinks for plant and animal wastes, but they also recycle nutrients for photosynthesis. The amount of dead material in a lake far exceeds the living material. Detritus is the organic fraction of the dead material, and can be in the form of small fragments of plants and animals or as dissolved organic material. In recent years, scientists have recognized that zooplankton grazing on [detritus](#) and its associated bacterial community represent an additional important trophic pathway in lakes.

Primary Producers

Much of modern limnological study revolves around the [primary productivity](#) of lakes. The ecology of plant growth is of great importance to the character and history of lakes and to all other organisms that live in lakes. The major threat to lakes involves the excessive growth of primary producers due to nutrient inputs caused by poor [landuse](#) management. Therefore, it is worth a closer look at these organisms.

The [littoral](#) zone is defined by the growth of rooted and floating aquatic plants, or [macrophytes](#). Figure 17 provides examples of common macrophytes found in Minnesota lakes. The macrophyte community can also include large [algae](#), such as *Chara*, *Nitelle*, or *Cladophora*. In shallow, clear lakes, macrophytes may represent most of the green plant material present and may account for most of the [photosynthesis](#).

SOME COMMON MACROPHYTES

click on the photos to see larger images



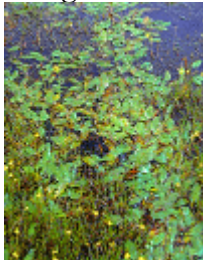








FLOATING			
	WATER LILY <i>Nymphaea</i>	DUCKWEED <i>Spirodela</i>	PONDWEED <i>Potamogeton</i>
			
SUBMERGENT	STONEWORT <i>Chara</i>	COONTAIL <i>Ceratophyllum</i>	BLADDERWORT <i>Utricularia</i>
			
	CATTAIL <i>Typha</i>	BULRUSH <i>Scirpus</i>	WILD RICE <i>Zizania</i>
EMERGENT			
	PURPLE LOOSESTRIFE <i>Lythrum salicaria</i>	EURASIAN WATER MILFOIL <i>Myriophyllum spicatum</i>	
EXOTICS			

Figure 17

Photos from the [University of Florida's Aquatic, Wetland, and Invasive Plant Information Retrieval System](#)

There may be few macrophytes in a lake when the bottom is too rocky or too sandy for the plants to anchor themselves, wave action too severe, or the water too deep. Also, sunlight may not reach the bottom even in shallow areas if the concentration of algae or silt is high.

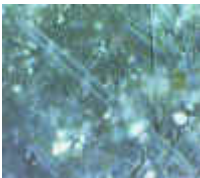
Algae constitute the other main group of primary producers (Figure 18). They come in countless forms and live in nearly all kinds of environments. Most are microscopic, growing as single cells, small colonies, or filaments of cells. Suspended algae are called [phytoplankton](#), while attached algae are called [periphyton](#). Phytoplankton grow suspended in open water by taking up nutrients from the water and energy from sunlight. If their populations are dense, the water will become noticeably green or brown and will have low transparency.

ALGAL PHOTOS

click on the photos to see larger images



Ankistrodesmus



Synedra



Cryptomonas



Spirogyra



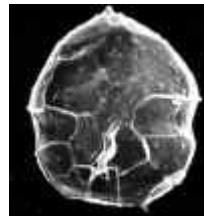
Dinobryon



Anabaena



Fragillaria



Peridinium



Aphanizomenon



Microcystis



Oscillatoria

Figure 18

Images courtesy of the [Susquehanna University Algal Image Archive and Cyanosite](#) (Purdue University).

Phytoplankton are classified into groups by the type of pigments they use to perform photosynthesis. While [chlorophyll](#)-a is common to all groups there are many other accessory pigments that allow the algae to capture different types of light. Green algae are considered the

most closely related to higher plants. Within this group alone there is a great diversity of size, shape, and growth form (single celled, colonial, filamentous, and flagellated). [Diatoms](#) belong to a large group, classified as the golden-brown algae, which also includes chrysophytes and dinoflagellates. The most striking characteristic of diatoms and chrysophytes is the ability to form silica (glass) cell walls. [Diatoms](#) cell walls are similar to a [petri dish](#), having two halves that fit together. Some chrysophytes have elaborate silica scales, spines, or vase-like shells called [loricas](#). Diatoms are [non-motile](#) (unable to swim), so they depend on water turbulence to remain suspended. Chrysophytes have [flagella](#) (whip-like appendages) that allow them to control their position in the [water column](#). There are other important algal groups containing [motile](#) forms.

Dinoflagellates are another group of golden-brown algae that also have flagella. These cells are capable of moving very rapidly; positioning themselves where light and nutrients are optimal for growth. Another flagellated group called the cryptomonads are very small algae and contain pigments that enable them to photosynthesize under very low light conditions, either very deep in the water column or during those times of the year when sunlight isn't very strong. Blue-green "algae" are technically referred to as [cyanobacteria](#) since, except for their chlorophyll-based photosynthesis, they are bacteria. They generally receive the greatest amount of research and management attention because of their ability to form [nuisance blooms](#) in [eutrophic lakes](#). It is important to remember, however, that blue-green algae are very important primary producers in both freshwater and marine systems, despite often being a nuisance.

Blue-greens have several characteristics that often enable them to dominate and create nuisance or noxious conditions. Some blue-green species have the ability to adjust their buoyancy. They can float or sink depending on light conditions and nutrient supply. All plants, including all algae, typically satisfy their nitrogen requirement by absorbing nitrate (NO_3^-) and/or ammonium (NH_4^+) from the water. However, some blue-greens can [fix](#) molecular nitrogen (N_2) derived from the atmosphere and dissolved in the water and convert it to ammonium in the cell through a process called [nitrogen fixation](#). This allows them to maintain high rates of growth when other forms of nitrogen are sufficiently depleted to limit growth by other types of algae. Blue-green algae typically are well-adapted to [phosphorus](#) deficiency because of their ability to absorb and store excess phosphorus when it is available -- enough to last days to weeks in some cases.

Unlike the green algae and diatoms, the blue-green algae are less suitable food for [primary consumers](#). This is partly because some blue-greens can form large colonies of cells embedded in a gelatinous matrix which may pose handling problems for [grazers](#). They also may produce chemicals that inhibit grazers or makes them "taste bad" to the grazers. Consequently, blue-greens have advantages over other algae at using nutrient and light resources, as well as avoiding being eaten.

Aphanizomenon flos-aquae is a common species of filamentous blue-green algae (see Figure 18) with the ability to regulate its buoyancy, fix nitrogen, form large inedible colonies, and form algal blooms. Other common bloom genera are *Anabaena* (N_2 -fixing filamentous algae) and *Microcystis* (colonial; not a N_2 -fixer). These bloom-forming algae are known to produce toxins in farm ponds that can poison cattle and, more recently, have been found to produce

potent neurotoxins and hepatotoxins that may be a greater public health concern than previously realized.

Chlorophyll-a Measure of Algae

An in-depth microscopic enumeration of the dozens of species of [algae](#) present in a [water column](#) each time a lake is sampled is prohibitively costly and technically impossible for most monitoring programs. Further, in many lakes a large portion of the algal [biomass](#) may be unidentifiable by most experts (these are appropriately called LRGTs or LRBGTs -- little round green things and little round blue-green things). However, measuring the concentration of [chlorophyll](#)-a is much easier and provides a reasonable estimate of algal biomass.

Chlorophyll-a is the green pigment that is responsible for a plant's ability to convert sunlight into the chemical energy needed to [fix](#) CO₂ into carbohydrates. To measure chlorophyll-a, a volume of water from a particular depth is filtered through a fine glass-fiber filter to collect all of the particulate material greater than about 1 micron (1/1000th of a millimeter) in size. The chlorophyll-a in this material is then extracted with a [solvent](#) (acetone or alcohol) and quantified using a spectrophotometer or a fluorometer.

Note regarding Water on the Web: Although the RUSS units do not currently have chlorophyll sensors, a prototype sensor is being developed by Apprise Technologies, Inc. and the [Natural Resources Research Institute](#) at the University of Minnesota Duluth. In the interim, surface water (0-2 meter composites) values of chlorophyll-a are being determined at 2-4 week intervals at Ice Lake and Grindstone Lake (by NRRI) and at two week intervals at Lakes Independence and Minnetonka during the ice-free season (by [Hennepin Parks Natural Resources](#)). These data, along with secchi disk depth data and ancillary nutrient data are posted on the WOW Web site as they become available ([Data/Other](#)).

Both chlorophyll-a and secchi depth are long-accepted methods for estimating the amount of algae in lakes. Secchi depth is much easier and less expensive to determine. However, care must be used in interpreting secchi data because of the potential influence of non-algal particulate material, such as silt from stream discharge or re-suspended bottom sediment. Also, the tea color of some lakes that's due to dissolved organic matter from bogs, can have an effect on secchi depth readings as well. Even if chlorophyll-a is measured, it may be important to also examine the algal community microscopically on occasion, since the mix of species may influence lake management decisions.

Algal Succession

A lake's biological characteristics are determined in large part by physical characteristics of the [water column](#). Important physical characteristics include temperature, light transparency, and wave action, as well as the total abundance of [inorganic](#) nutrients, which is largely a watershed characteristic. In addition, preceding populations influence successive populations by assimilating critical nutrients. Populations also have varying susceptibilities to grazing by [zooplankton](#), which vary seasonally in type and abundance. As physical, chemical, and biological conditions in the lake change over time, some species will be effectively eliminated from a lake because they cannot tolerate the new conditions. Other species will be out-competed by organisms that are better adapted to the new environment.

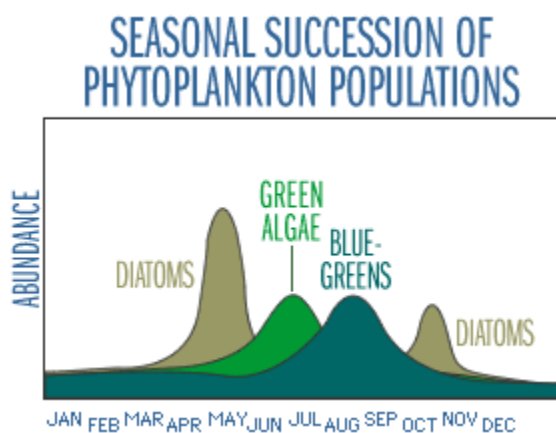


Figure 19

These changes represent an important ecological pattern in lakes known as algal succession. In most natural systems the seasonal succession of [algae](#) (and macrophytes) is a recurrent, if not exactly repetitive, yearly cycle. A typical algal succession is shown in Figure 19. Some species flourish for a period of time and then give way to other species more compatible with changed conditions, such as warmer water, more daylight, or lower concentrations of [phosphorus](#) or nitrogen. Short-lived plankton communities are characterized by these seasonal fluctuations; longer-lived organisms, such as fish, must be tolerant of lake conditions all year.

Consumers

[Zooplankton](#), small animals that swim about in open water (Figure 20), are [primary consumers](#). They graze on [algae](#), bacteria, and [detritus](#) (partially decayed [organic](#) material). Some species can be seen with the naked eye, although they are more easily observed with a hand lens or low-power microscopes. If you wish to see them, stare into the water of a pond or lake on a calm night with a flashlight beam shining from above. [Secondary consumers](#), such as planktivorous fish or predaceous invertebrates, eat [zooplankton](#). While [photosynthesis](#) limits plant growth to the sunlit portions of lakes, [consumers](#) can live and

grow in all lake zones, although the lack of [oxygen](#) ([anoxia](#)) may limit their abundance in bottom waters and sediments.

ZOO PLANKTON

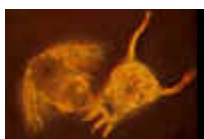
click on the photos to see larger images



Daphnia Pulicaria



Diaptomus



Keratella (right imange)



Chaoborus

Figure 20

Images courtesy of University of Minnesota Limnology

[Benthic](#) organisms are major consumers and are also important recyclers of nutrients otherwise trapped in the sediments. [Benthic](#) organisms include invertebrates and bottom-feeding fish. Their feeding strategies vary widely. Some, such as clams, filter small bits of organic material from water as it flows by. Others eat detritus that has sunk to the bottom. The spread of the exotic invader, the zebra mussel, has caused dramatic changes in the water quality and ecology of Lake Erie in the past decade due to its high rates of filtration and high reproductive rate (See [Ohio Sea Grant](#)).

Not all organisms are easily classified as planktonic or benthic. For example, *Chaoborus*, [Dipteran](#) insect larvae, remain near the sediments in daytime and migrate to upper waters at night. These transparent predators ("phantom midges") migrate upward to feed on zooplankton, and are, themselves, a favorite food for fish. Mysid shrimp behave in a similar fashion and have been shown to migrate enormous distances (>100 meters) in Lake Tahoe each night.

The best known group of aquatic consumers is fish. Many small fish, such as sunfish and perch, primarily eat zooplankton. [Tertiary consumers](#) that prey on the smaller fish include larger fish and other carnivorous animals (loons, grebes, herons, and otters). Different species exploit different habitats (niches). Bass and pike are found in lakes that have beds of aquatic [macrophytes](#) suitable for spawning. Walleyes, on the other hand, spawn on a gravel bottom. Lake trout live only in very clear lakes with cold, well-oxygenated deep water. In contrast, carp are adapted to warm turbid, low oxygen lakes with mucky, high organic matter bottoms. View images of fish, [Figure 21](#).

Decomposers

Decomposers, which include bacteria, fungi, and other microorganisms, are the other major group in the [food web](#). They feed on the remains of all aquatic organisms and in so doing break down or decay organic matter, returning it to an [inorganic](#) state. Some of the decayed material is subsequently recycled as nutrients, such as [phosphorus](#) (in the form of phosphate, PO_4^{-3}) and nitrogen (in the form of ammonium, NH_4^+) which are readily available for new plant growth. Carbon is released largely as [carbon dioxide](#) that acts to lower the [pH](#) of bottom waters. In [anoxic](#) zones some carbon can be released as methane gas (CH_4). Methane gas causes the bubbles you may have observed in lake ice.

The decomposers can be found in all biological zones of a lake, although they are the dominant forms in the lower [hypolimnion](#) where there is an abundance of dead organic matter. Oxidation of organic matter by the decomposers (respiration) in the hypolimnion is responsible for the depletion of [dissolved oxygen](#) over the course of the summer, potentially leading to anoxic conditions (no dissolved oxygen). There is no source of oxygen in the hypolimnion to replace oxygen lost through [decomposition](#). [Stratification](#) prevents atmospheric oxygen from being mixed deeper than the [thermocline](#), and it is usually too dark for photosynthesis. Consequently, a large volume of organic matter from a variety of sources (e.g., wastewater, sinking algae, dying macrophytes, and organic sediment washed in from the watershed) leads to faster oxygen depletion and often complete removal of oxygen in the hypolimnion. The resulting [anoxia](#) has a profound effect on both the chemistry and the biology of the lake.

Trophic Status

Since the early part of the 20th century, lakes have been classified according to their trophic state. "[Trophic](#)" means nutrition or growth. A [eutrophic](#) ("well-nourished") lake has high nutrients and high plant growth. An [oligotrophic](#) lake has low nutrient concentrations and low plant growth. [Mesotrophic](#) lakes fall somewhere in between eutrophic and oligotrophic lakes. While lakes may be lumped into a few trophic classes, each lake has a unique constellation of attributes that contribute to its trophic status. Three main factors regulate the trophic state of a lake:

1. Rate of nutrient supply

- Bedrock geology of the watershed
- Soils
- Vegetation
- Human [landuses](#) and management

2. Climate

- Amount of sunlight
- Temperature
- [Hydrology](#) (precipitation + lake [basin turnover time](#))

3. Shape of lake basin ([morphometry](#))

- Depth (maximum and mean)
- Volume and surface area
- Watershed to lake surface area ratio ($A_w : A_o$)

Trophic status is a useful means of classifying lakes and describing lake processes in terms of the [productivity](#) of the system. Basins with infertile soils release relatively little nitrogen and [phosphorus](#) leading to less productive lakes, classified as [oligotrophic](#) or [mesotrophic](#). Watersheds with rich organic soils, or agricultural regions enriched with fertilizers, yield much higher nutrient loads, resulting in more productive, [eutrophic](#) (even hyper-eutrophic) lakes.

Eutrophication, the progress of a lake toward a eutrophic condition, is often discussed in terms of lake history. A typical lake is said to age from a young, oligotrophic lake to an older, [eutrophic lake](#). Geological events, such as glaciation, created lakes in uneven land surfaces and depressions. The landscapes surrounding lakes were often infertile, and thus many lakes were oligotrophic. Eventually some of the [shoreline](#) and shallow areas supported colonizing organisms that decomposed unconsolidated materials into reasonably fertile sediments. Active biological communities developed and lake basins became shallower and more eutrophic as decaying plant and animal material accumulated on the bottom. Shallow lakes tend to be more productive than deep lakes, in part because they do not stratify, thereby allowing nutrients to remain in circulation and accessible to plants. They also tend to have a smaller lake volume, so nutrient loading from their watershed has a larger impact. There are undoubtedly exceptions to this typical progression from oligotrophy to eutrophy, where geology, [topography](#), and lake morphology caused eutrophic conditions from the start.

This concept of lake aging has unfortunately been interpreted by some as an inevitable and irreversible process whereby a lake eventually "dies." In fact, many oligotrophic lakes have persisted as such since the last glaciation and some ultra-oligotrophic lakes, such as Lake Tahoe may have been unproductive for millions of years. Furthermore, research in [paleolimnology](#) has provided evidence that contradicts the idealized version of a lake becoming more and more eutrophic as it ages. Studies of sediment cores have suggested that the algal productivity of Minnesota lakes actually may have fluctuated a great deal during the past 12 - 14,000 years (the period since the last glaciation). Changes in climate and watershed vegetation seem to have both increased and decreased lake productivity over this period. Some lakes probably experienced high rates of [photosynthesis](#) fairly soon after glacial retreat and then became less productive until recent times. It is also possible that water sources for some lakes have changed over the past thousands of years through diversions of stream flow, for example. In such cases water supplies to a lake (and therefore nutrient supplies) could have changed, leading to changes in the lake's productivity.

However, lakes may be culturally eutrophied by accelerating their natural rate of nutrient [inflow](#). This occurs through poor management of the watershed and introduction of human wastes through failing septic systems. Such changes may occur over periods of only decades and are reversible if [anthropogenic nutrient loading](#) can be controlled. In the 1960s this was a serious issue, exemplified by the hyper-eutrophic condition of Lake Erie. Although it was pronounced

"dead," it eventually returned to less eutrophic conditions, when major point sources of phosphorus were controlled in the early 1970s (by spending millions of dollars to build advanced wastewater treatment plants).

In North America, most of the problems associated with the direct discharge of domestic wastewater have been successfully mitigated. Now the regulatory focus is on the much more difficult problem of controlling [non-point sources](#) (NPS) of nutrient pollution such as agricultural drainage, stormwater runoff, and inadequate on-site septic systems. NPS pollution is particularly difficult to address because it is diffuse, not attributable to a small number of polluters, and associated with fundamental changes in the landscape, such as agriculture, urbanization and shoreline development.

Biological Differences

Populations of [algae](#) and the animals that feed on them are lower in [oligotrophic](#) lakes because of low nutrient concentrations. Thus the water remains clear. Decay of the relatively small amount of [organic](#) matter in oligotrophic lakes does not completely deplete the hypolimnetic supply of [dissolved oxygen](#). Therefore, lack of oxygen does not restrict animals from living in the [hypolimnion](#) of oligotrophic lakes. Lake trout, for example, require cold, well-oxygenated water and primarily live in the hypolimnion of oligotrophic lakes. Minnesota's oligotrophic lakes are found in the northeast region of the state, where infertile soils are covered with mixed conifer forests.

Extremely deep oligotrophic lakes such as Lake Superior and Lake Tahoe have hypolimnia that remain completely saturated with [oxygen](#) the entire year. However, many moderately deep lakes (with maximum depths greater than about 30 meters) may develop [anoxia](#) in the lower hypolimnion during late summer but may still be classified as oligotrophic because of their very low nutrient concentrations, low algal abundance, and relatively high transparency (high secchi depth). These lakes may have a [two-story fishery](#), with warm and cool water fish in the [epilimnion](#) and [metalimnion](#) and cold water fish (such as trout) in the cold, oxygen rich portion of the hypolimnion. The cold-water fishery is therefore very sensitive to increased inputs of organic matter from sewage or erosion (external inputs), and to increased algal and macrophyte production (internal inputs) due to [eutrophication](#) since these factors will accelerate the rate and extent of [hypolimnetic oxygen depletion](#) in the summer.

Algae or [macrophytes](#) grow so thickly in some [eutrophic lakes](#) that light penetrates only a short distance and nutrients below that depth are not assimilated. As discussed earlier, [phosphorus](#) is typically the limiting nutrient in freshwater lakes, meaning that the plants deplete all available phosphorus before depleting other nutrients. In a hypereutrophic lake, algae may become so abundant that they suffer from self-shading. In those cases, [photosynthesis](#) is limited by light rather than by nutrients. When a great abundance of phosphorus is available in a lake, nitrogen may become limiting. In such lakes, certain species of blue-green algae that can [fix](#) atmospheric nitrogen have a clear competitive advantage and frequently become dominant. They dominate the algal community until another nutrient, or usually light, becomes limiting. In many infertile lakes in northeastern Minnesota, both phosphorus and nitrogen may be extremely low during

midsummer. Since most sources of either point source or nonpoint-source pollution involve increased inputs of **both** N and P, these lakes are extremely sensitive to such pollution, irrespective of which is technically "most" deficient.

Eutrophic lakes show wide seasonal changes in their biological and chemical conditions. Because of the great amount of organic matter produced in these lakes, the decay rate is high in the hypolimnion, causing oxygen to be depleted. Therefore, eutrophic lakes frequently show a complete loss of dissolved oxygen below the [thermocline](#) during summers. Clearly, fish and most other animals cannot live in the hypolimnion of such lakes. Warm-water fish that can live in the epilimnion, however, can be quite productive. Bass, panfish, northern pike, walleye, carp, and bullheads thrive in many of Minnesota's eutrophic lakes. Complete or nearly complete oxygen depletion below the thermocline may also be a common feature of many moderately deep (10 to 30 m) [mesotrophic](#) lakes, if deep enough to stratify throughout the summer. Therefore, virtually complete anoxia below the thermocline does not necessarily mean that the lake is eutrophic.

Ice Lake, one of our WOW lakes, is an example of a mesotrophic lake that becomes [anoxic](#) below the thermocline in the summer, (see [Ice Lake](#) section) as is Hale Lake, a somewhat less productive lake immediately downstream of Ice Lake. Both are ~16-18 meters deep.

Another oxygen-related problem in eutrophic lakes is [winterkill](#). A dense snow cover over the ice reduces light penetration and keeps oxygen-producing photosynthesis from occurring. The high organic content of the water, however, provides considerable food for the decomposers. If the decomposers succeed in using all the available dissolved oxygen, a fish kill can occur.

In certain cases, a winterkill may lead to a more balanced fishery and possibly even improved water quality. Fish that survive a winterkill will have reduced competition for food for a period of time and so may grow faster and to a larger size. Fewer small fish reduces predation on the larger [zooplankton](#), such as the water flea, *Daphnia sp.*, leading to increased zooplankton grazing on algae and a resultant increase in water [clarity](#). This general scheme, involving fishery manipulations to reduce the abundance of zooplanktivorous fish, has been termed [biomanipulation](#), and is being tried in many urban lakes where it is economically impractical to reduce nutrient inputs enough to significantly reduce algae. In these situations the offending fish may be removed by intense stocking of gamefish, by intensive netting and trapping, or even by poisoning the entire fishery and starting over with greatly reduced [planktivores](#).

Aquatic Ecology And The Food Web



Some Understanding of the aquatic ecosystem is necessary before fisheries managers or pond owners can begin to understand changes in fish populations. The aquatic ecosystem is a complex of interrelated species and their reaction to each other and their habitat.

Changes in one part of the system often cause changes, large and small, throughout the system.

Eradication of aquatic plants in a pond with a healthy largemouth bass population is a good example of this concept. When all plants are eliminated from the pond in an effort to improve angling access; forage fish such as bluegill lose their protective cover and are exposed to excessive predation by largemouth bass. Bass initially respond by growing and reproducing rapidly, however, as the forage fish population declines, the once healthy bass population, limited by declining food supplies, becomes numerous, small and stunted.

The basic ecological concepts discussed in this section will provide the pond owner with the knowledge necessary to understand the reasoning behind fish and plant management techniques.

Succession

The aquatic ecosystem is a dynamic, changing environment. Daily and annual bio-geo-chemical cycles drive changes in water chemistry and the species composition of aquatic communities.

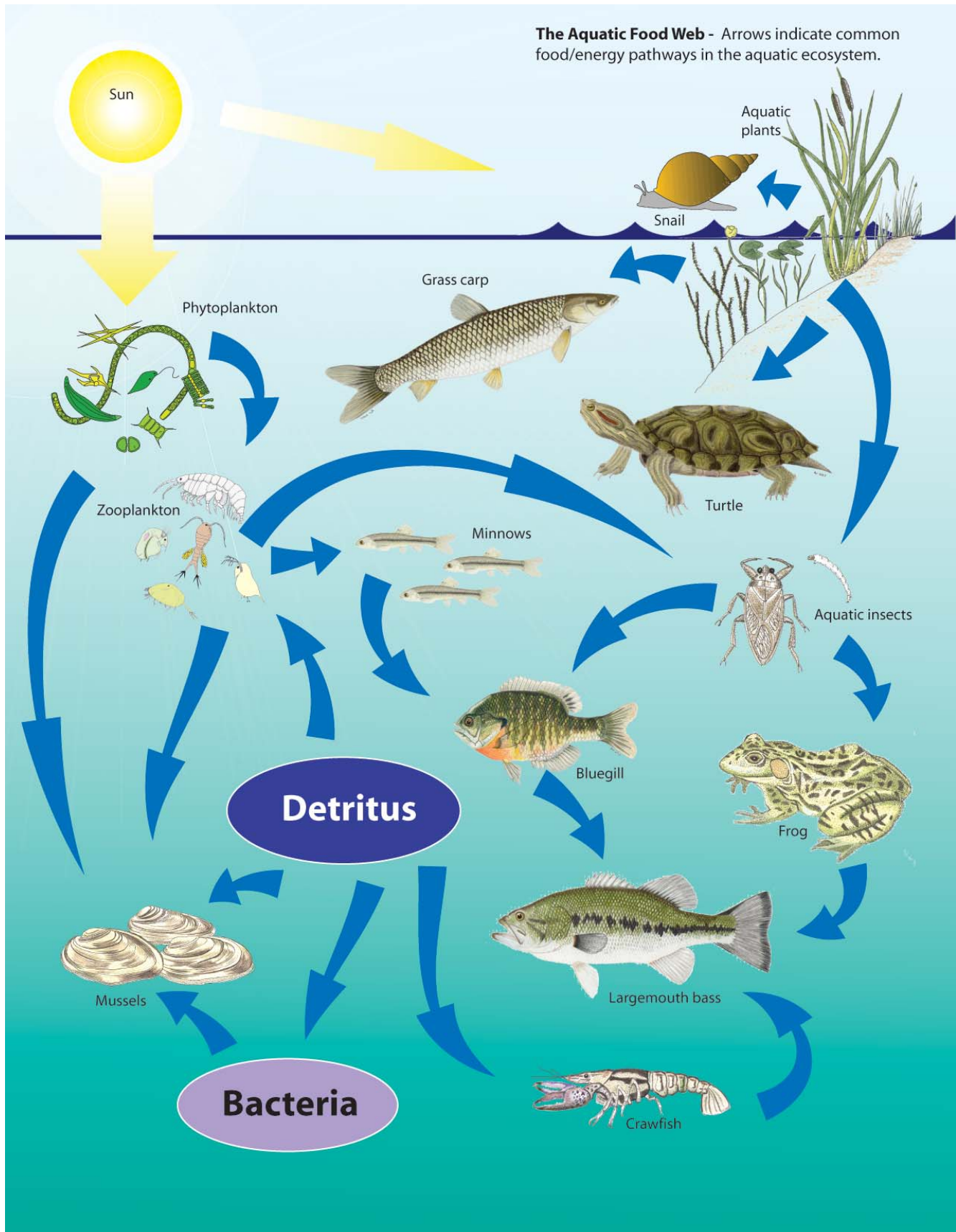
Ponds and lakes go through a cycle of changes over time, from newly created aquatic environment back to terrestrial habitat.

New ponds and lakes are usually **oligotrophic**. Oligotrophic waters have very little nutrients, a small phytoplankton population and consequently, clear water unless it is colored by dissolved or suspended minerals.

As the pond ages, leaves and other material wash into it from the watershed and plants and animals die and decay; gradually increasing the amount of nutrients available to the ecosystem. The phytoplankton community increases and the water becomes less clear and more green. Vascular aquatic plants colonize the shoreline and extend into the water as nutrients become available. Lakes with high levels of nutrients are said to be **eutrophic**. The pond has reached a mature stage of development.

Highly eutrophic or polluted lakes can result from activities in the watershed that release plant nutrients. Farm fertilizers, livestock manure, some detergents or other waste material containing nitrogen or phosphorous washing into the water produce noxious algae blooms and excessive phytoplankton production that is characteristic of this condition.

Over time, leaves, dead plants and animals and other detritus accumulates on the pond bottom. The pond becomes progressively shallower to the point that light penetrates all areas of the pond bottom and



aquatic vegetation covers the waters surface. The pond has reached the age of **senescence**. Willows, cypress, cattail and other shoreline plants advance toward the ponds center.

Eventually rooted plants cover the pond bottom and the pond becomes a bog or marsh. Dry land trees begin to invade areas that were once under water. The marsh eventually fills in and dries up. Surrounding terrestrial vegetation replaces aquatic and semi-aquatic plant species and succession is complete. This successional cycle can be disrupted at any time by natural events such as floods that can scour, deepen and rejuvenate the pond. Human activity such as draining and dredging the pond also can interrupt the successional cycle.

Energy movement in the aquatic ecosystem

An ecosystem can be thought of as a conduit of energy derived from sunlight. Energy from the sun plus inorganic materials are the basis of all life. Energy can not be recycled. It moves through the ecosystem and ultimately dissipates as heat. Energy transfer efficiencies are low, usually about 10 % between each trophic level of the ecosystem.

Trophic levels contain groups of organisms with similar methods of food (energy)consumption. Energy moves from one trophic level to the next through the **food web** fig. 1. An example of a common, linear aquatic food chain is:

Phytoplankton (microscopic plants) - Zooplankton (microscopic animals) -Insects - Blue gill - Largemouth Bass -Turtle -Bacteria

In reality, most food chains are usually complex and interconnected. They are more accurately described as **food webs**.

Producers are the first trophic level in the ecosystem and form the base of the food chain. Producers obtain nutrition from inorganic materials and sunlight energy. In aquatic

ecosystems phytoplankton are the primary producers; other aquatic plants also contribute but to a lesser extent. The total amount of energy per unit of time fixed as plant tissue is called **primary production**. Plants are able to convert only about 1-2 percent of the available sunlight energy into chemical energy usable for plant production.

Each time energy passes from one trophic level to the next, for example, a grass carp eating an aquatic plant or a largemouth bass consuming a bluegill, about 90 percent of the energy will be lost. Consequently, ecosystems require a large base of primary production to support a relatively modest level of production at higher trophic levels. The Eltonian trophic pyramid shown in fig. 2 illustrates this concept graphically.

Light is needed for all plant growth. Because clear ponds allow light penetration to greater depths than muddy ponds, more phytoplankton and other plants can grow, resulting in greater primary production in the base of the food chain.

More production in the food web base allows more production through out the aquatic ecosystem; and consequently, greater natural fish production in clear ponds than in muddy ponds.

Fish production in muddy ponds can be increased by clearing the pond or by addition of supplemental fish food to compensate for lack of primary production.

Fish production in clear ponds can be increased

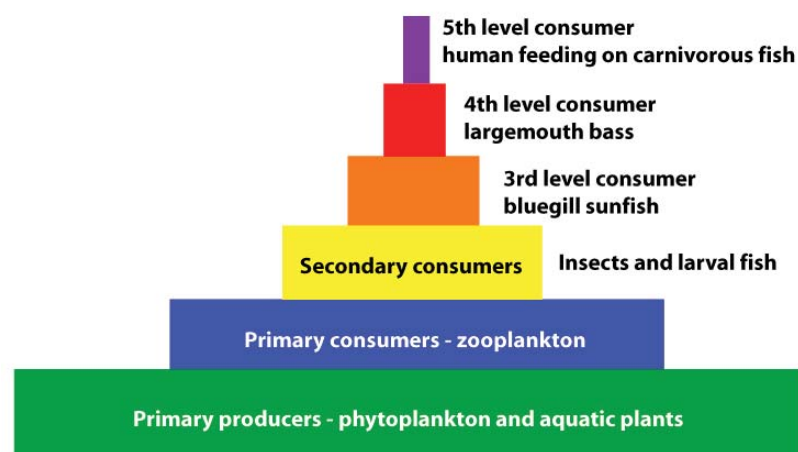


Figure 2. An Eltonian pyramid depicting relative abundance of organisms at six trophic levels.

by the addition of plant fertilizers to stimulate primary production. Fertilization only improves fish production if plant nutrients are lacking and light penetration is sufficient to allow increased plant growth. (When a specific factor is not available in sufficient quantity and restricts the growth of organisms it is called a **limiting factor**. For example, light is a limiting factor for plant growth in muddy ponds.)

In most situations, nutrients are actually over abundant, due to livestock waste or farm fertilizers. An over abundance of nutrients in clear ponds results in green, phytoplankton rich water; or excessive growth of rooted aquatic plants.

Consumers make up the next trophic level; and must eat other organisms to obtain their energy. Consumers, in turn, occupy different trophic levels. Trophic levels of common aquatic organisms are shown in table 1.

Primary consumers are herbivores, they eat plants. In our aquatic ecosystem example, zooplankton feeding on phytoplankton occupy the primary consumer trophic level. Cattle are primary consumers in terrestrial ecosystems.

Secondary consumers, represented by certain aquatic insects are carnivores and feed upon primary consumers, the zooplankton.

Our example also includes a **tertiary consumer**, the largemouth bass that feeds upon other carnivores.

The turtle, although opportunistic in its feeding

habits, is represented in the example as a **scavenger**. Organisms at this trophic level feed on large bits of dead or decaying organic matter.

Organisms of the final trophic level break down organic matter and animal waste products. These creatures are called **decomposers**, and they break down organic material back to its constituent elements. Bacteria are the most numerous and important decomposing organisms.

Ecological pyramids can be constructed using numbers of organisms, energy consumption in the

Trophic levels and feeding habits of common aquatic organisms.

Organism	Trophic level	Foods
Phytoplankton	Primary producers	Sunlight energy and dissolved nutrients
Zooplankton	Primary consumers	Phytoplankton, bacteria and detritus
Bacteria	Decomposers	Chemical molecules / detritus
Snails	Primary consumer scavenger, herbivore	Detritus / plant material
Mussels	Primary consumer filter feeders	Phytoplankton, zooplankton, detritus
Red eared slider turtle	Herbivore, scavenger	Plants, decomposing organic matter, sometimes fish
Crayfish	Scavengers, carnivore	Decomposing organic matter, fish, insects, opportunistic
Common carp	Herbivore	Plants, organic matter
Channel catfish	Scavenger, carnivore	Carrion, small fish
Largemouth bass	Carnivore	Fish, insects, frogs, crayfish
Frog	Carnivore	Insects, fish

ecosystem or total biomass to visually illustrate relationships and relative abundance of organisms among trophic levels.

The first trophic level which includes algae, phytoplankton and aquatic vascular plants, usually makes up the bulk by weight of organisms (about 85%) in natural aquatic ecosystems and forms the base of the food chain. (In some systems bacteria may actually be more abundant than plants.) Because there is up to a 90 percent loss of energy in each step of the food chain, each higher level of consumer will constitute a correspondingly lower amount of the total weight of living organisms in the pond. For example, about 100 lbs of insects, crayfish and small fish are required to produce 10 lbs of bluegill sunfish; and about 8 -10 lbs of bluegill sunfish are required to produce 1 lb of largemouth bass. This ecological fact explains why there are usually more than 10 times as many prey animals as there are predators. This is also the reason why ponds and lakes can not produce large numbers of big bass without an adequate forage base.

The same principle explains why muddy ponds, containing little phytoplankton can not produce as many pounds of fish per acre as a clear pond filled with phytoplankton, algae and vascular plants. The base of the food chain in a muddy pond is not large enough to support large populations of fish.

Many aquatic organisms occupy more than one trophic level and also feed on a variety of foods items from different trophic levels. Thus the concept of the ecological pyramid though useful, does not fully explain the complexities and interrelationships that exist among organisms in the pond.

Individual organisms and their roll in the aquatic community

An organism's **niche** includes all of the characteristics of its way of life. It includes the animal's habitat, physical and chemical tolerance limits, food, behavior and habits. Niche can be thought of as having multiple dimensions that define the organism's place in the environment. Aspects of a species ecological niche can be plotted on a graph to

visually show how the animal fits into its community. Plots can include temperature tolerance, oxygen requirements, food requirements, habitat preferences or any other aspect of interest concerning a particular species (fig. 3) .

Niches of different species may overlap to varying degrees. Overlapping niches usually result in competition among species. Two species with the same niche requirements for food will compete for this resource. Closely related species may have very similar niches, however, it is rarely possible for two different species to have identical niches. One species will eventually out compete the other. This theory is known as the **competitive exclusion principle**.

It has not been proven to be universally true although documented incidences of competitive exclusion have been observed. Two species with identical niche requirements could coexist in a habitat that contained essentially unlimited resources necessary for survival and reproduction.

Niches also can overlap only during certain life stages. For example, young bluegill and young green sunfish may compete for similar sized food items.

Species with overlapping niches may reduce competitive pressures by diversifying or partitioning the niche. Niche partitioning or diversification is accomplished in many ways. A common food resource may be used during the day by one species and at night by another; for example, hawks may feed on mice during the day while owls feed on them at night.

The aquatic habitat

Changes in light penetration and plant growth dictate much of the habitat variety found in the aquatic ecosystem.

The **benthic** or bottom dwelling aquatic communities begin at the shore line and extend to the deepest parts of the pond. Many bacteria, phytoplankton and protozoa live between the damp particles of sand and soil. Sedge species, bullrush and cattail also colonize the area and often extend out into the pond to depths of 4 feet or more.

The **littoral zone** extends into the body of water from the shore to the deepest area of rooted plant growth. The extent of the littoral zone depends on water clarity, light penetration and wave action. The littoral zone must have adequate light for photosynthesis.

The depth of this zone in your pond can be roughly calculated by lowering a white coffee cup on a string into the water and measuring the depth at which it just disappears. Multiply this depth by 2.75 to estimate the depth of the deepest rooted plants in the pond.

The littoral zone contains a large and diverse community of aquatic organisms. Vascular aquatic plants in this region support a variety of insects, snails, crawfish, mussels, frogs, turtles, larval fish and their predators. Many of the mobile organisms

such as turtles and fish occupy more than one habitat zone.

Below the littoral zone is the **sub-littoral** region. This habitat is characterized by accumulations of

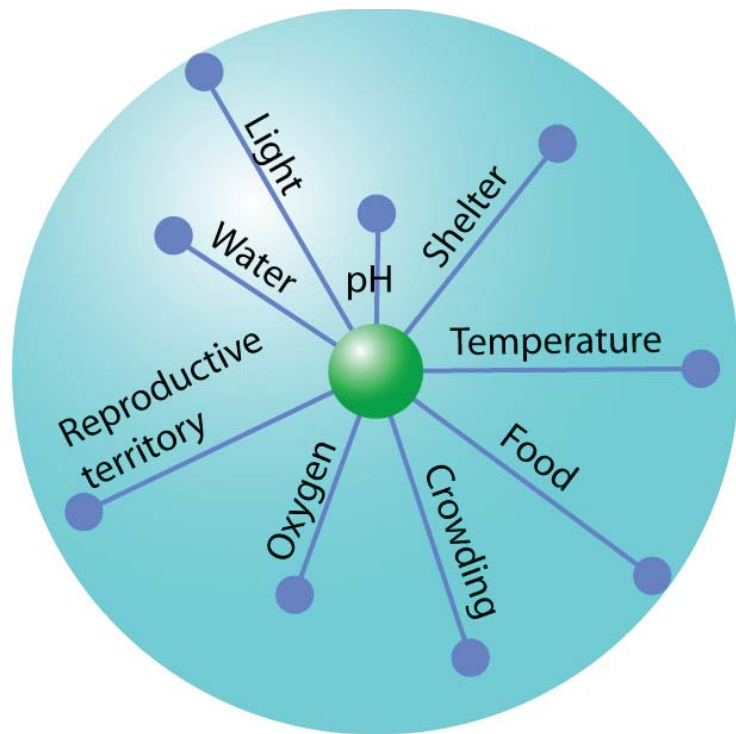


Fig. 3 Multi-dimensional niche space.

crustacean, mussel shells, and some dead plant material. This region is well oxygenated but poorly lighted. Fewer species are found here than in the littoral zone.

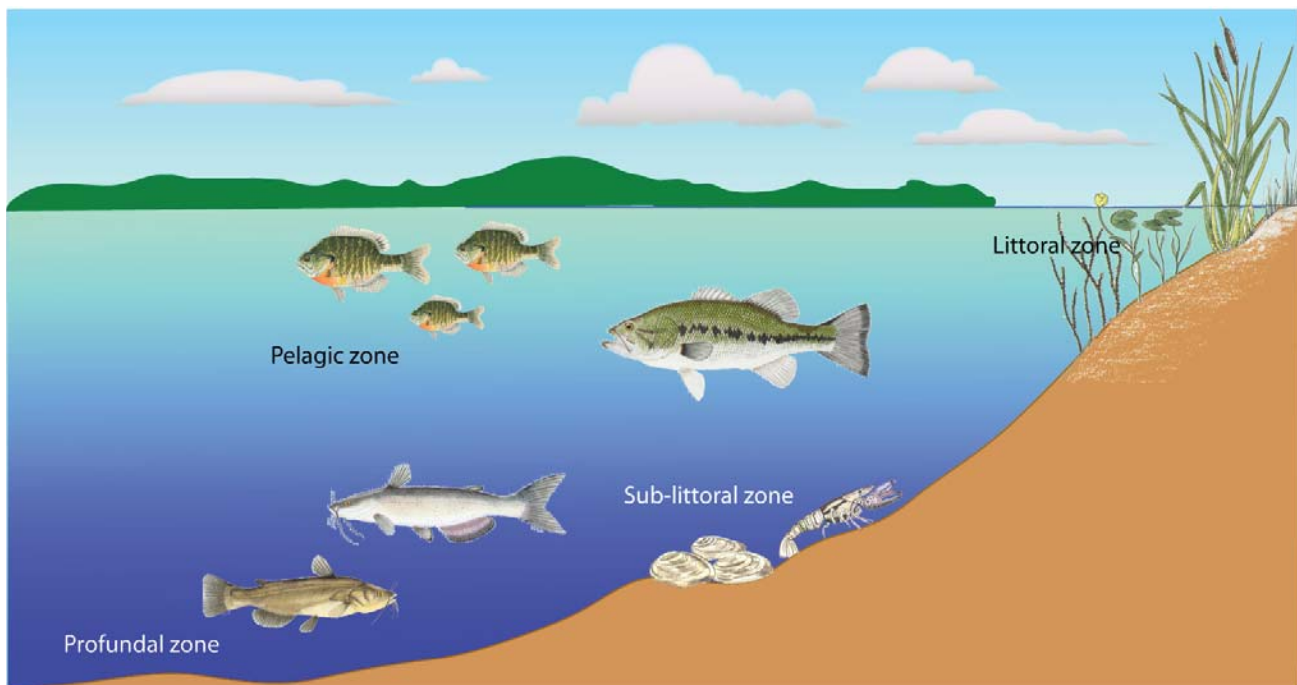


Fig. 4 Aquatic habitat zones in freshwater lakes and ponds.

In ponds large enough to thermally stratify, a profundal zone exists. The **profundal zone** is usually a stable environment except during periods of pond turn over. Oxygen levels are low or absent and there is little light penetration and no plant growth. Water temperature is usually cool and fluctuates little. The profundal zone is composed of detritus, and the bacteria and other organisms that feed on and decompose this material.

The open water is known as the **pelagic zone**. Plankton and other free swimming or drifting plants and animals inhabit this region as well as fish and other large, mobile organisms.

ENVIRONMENTAL MODIFICATIONS

The natural foods of fish are either produced in the pond, washed in by rain, or fall into the pond. Food produced in the pond has its origins in the nutrients found in the pond. A variety of plants, from microscopic algae to rooted plants, use these nutrients to grow. In turn, the plant material can be eaten by microscopic zooplankton or aquatic insects. These organisms are then eaten by bluegills and young bass. Bigger bass may then eat these smaller fish. Bass will also eat other items, such as crayfish and frogs, which also rely on plant material and insects in the pond for food. A pond has a series of food chains, or more accurately a food web, that starts with nutrients in the watershed and ultimately ends with big fish. Small fish concentrate the energy taken from the food they eat and, in return, become a high-energy food for larger fish. A pond will support 5 to 10 times as many pounds of bluegills as it does bass because bluegills are lower on the food chain.

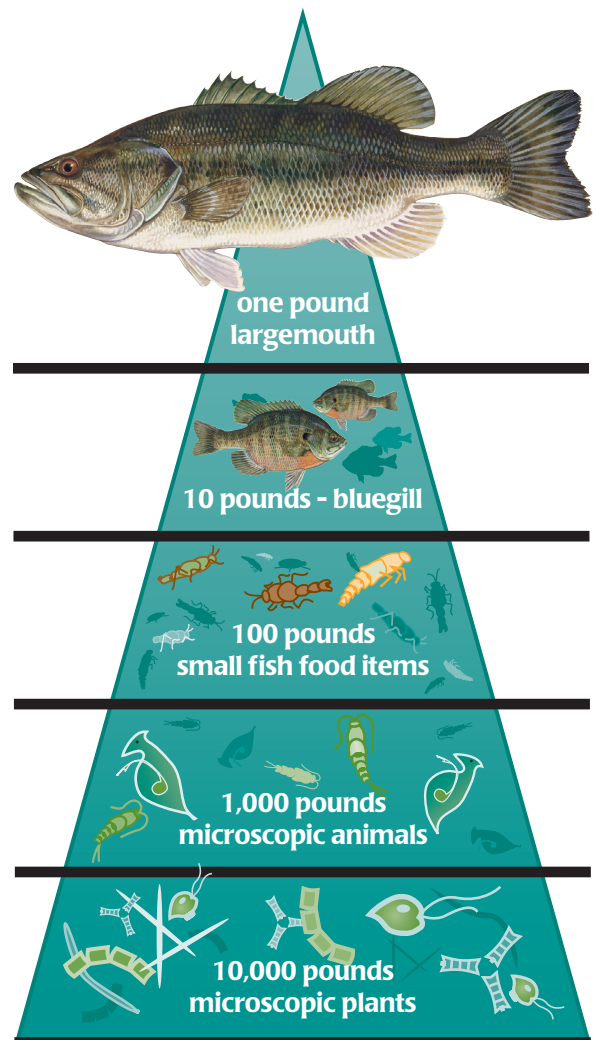


The total weight of fish that a pond can support is called the carrying capacity.

Much like a pasture can only support so many cattle, or a garden can only grow so many vegetables, a pond can only support a certain biomass, or weight, of fish. A pond will achieve its maximum carrying capacity about 3 to 4 years after it is initially stocked. Without supplemental feeding, an average pond in Nebraska supports about 250 pounds of fish per acre: about 190 pounds of bluegill, 35 pounds of bass, and 25 pounds of catfish and/ or other species. Once the carrying capacity is reached, fish growth rates decline. Individual populations can be



AQUATIC FOOD CHAIN



comprised of many small fish, or a few large ones, but the total weight will be the same and equal what the pond can support.

The wildlife productivity of a pond and the immediate surrounding land can be increased by making beneficial environmental modifications, or supplementing what is already present, depending on management goals. These changes can involve manipulating aquatic and terrestrial habitats that will then benefit associated wildlife, whether it is a rabbit, a small catfish, or even a dragonfly.

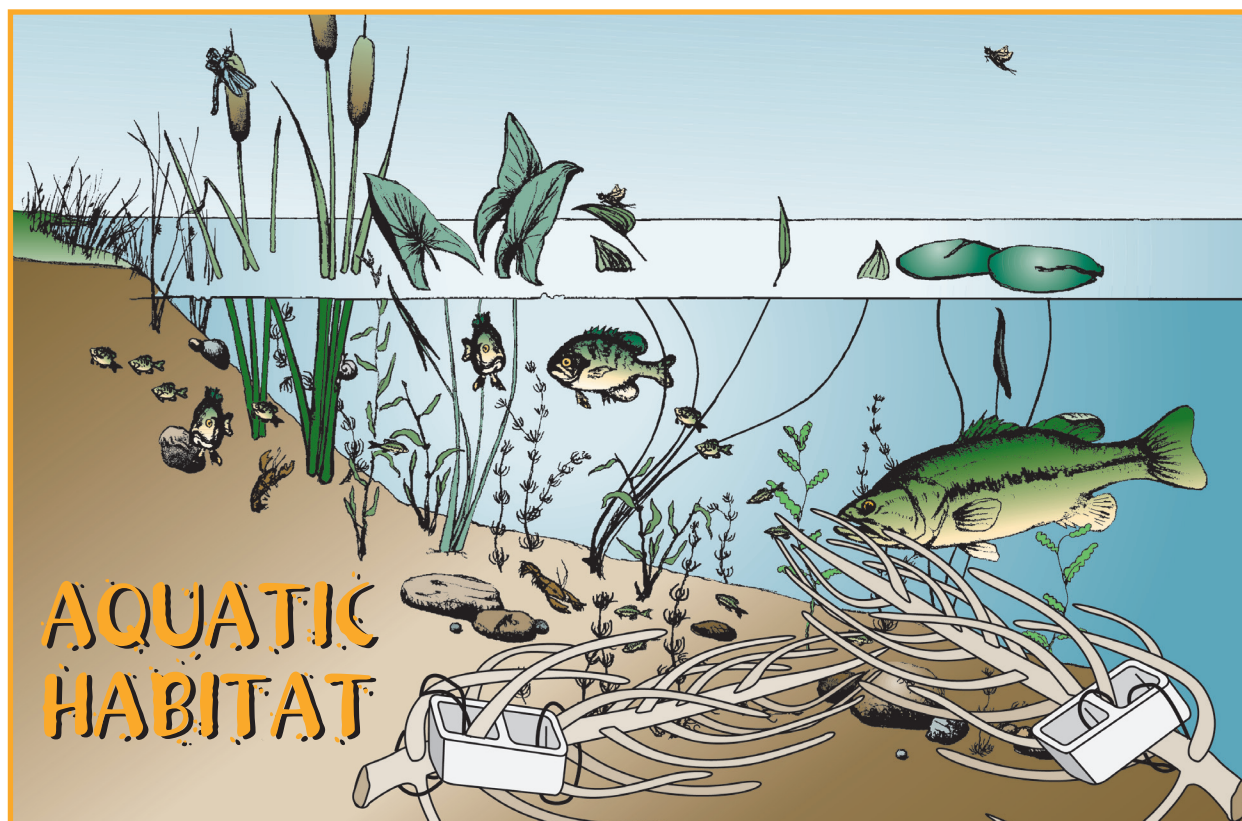
Aquatic Habitat

Trees and brush removed during construction can be returned to the pond basin before the pond fills. After a new pond fills, the flooded trees, brush, grasses, and weeds become underwater structures and create an excellent, nutrient-rich environment for aquatic life. Underwater structures provide shade and cover for fish, substrate on which aquatic organisms,

such as aquatic insects, can grow and feed, and concentrate fish. Small fish will come to the cover to eat the insects found there, and bigger fish will come to eat the small fish. However, as the pond ages, inundated vegetation eventually decays and disappears, reducing the amount of fish a pond can support. Some of the natural effects of aging and subsequent habitat loss can be counteracted by encouraging development of natural habitat and/or the addition of cheap, but sometimes labor-intensive, artificial habitat.

Natural Habitat

Aquatic vegetation is also considered structure and will eventually become established in most ponds. A good fishing pond usually will be about 40% covered with emergent and submergent aquatic vegetation. Aquatic vegetation is often considered a nuisance and removed by pond owners. It is, however, a natural and necessary component of a healthy pond. Aquatic plants provide cover, food, and



nesting sites for fish and other organisms. They also help to oxygenate the water, reduce nutrient levels, and improve water clarity by decreasing wave strength and minimizing shoreline erosion. Emergent and submergent vegetation tie up a portion of the nutrients present in a pond, which reduces the likelihood of nuisance planktonic algae blooms that can cause fish kills.

Although emergents – rigid plants which have the bulk of the plant above the water and grow along the shoreline – can become established naturally in a pond, they can also be transplanted to speed colonization. Most emergents, especially cattail, bulrush and arrowhead, are relatively easy to transplant. This should be done in the spring when new growth starts. Rootstock can be dug up and cut or pulled apart and planted along the shoreline. Make sure at least two new shoots/nodes are present for each section when utilizing cattails. Some of the transplants should be placed adjacent to and immediately above the water line, while others can be placed in water less than 10 inches deep. Cattails are very aggressive and can spread over extensive shoreline areas. Mechanical or chemical means may be necessary to eliminate them in wading, swimming, and some fishing areas.

Even though submergents – non-rigid plants which are normally completely submerged and attached to the bottom – can also be transplanted, they usually become established

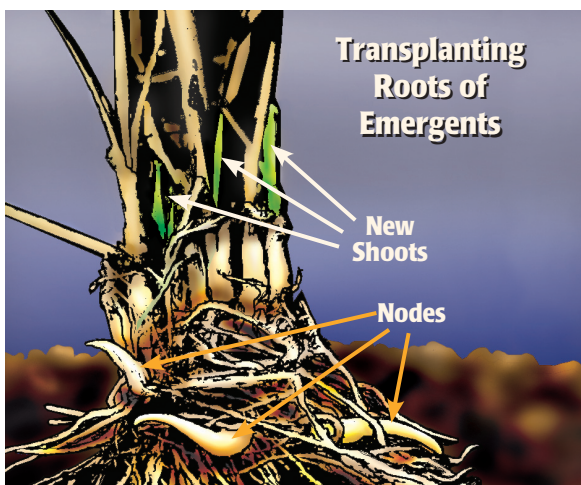


See page 61 for additional information on identification, benefits, potential problems, and control of aquatic vegetation.

in the pond naturally by waterfowl transporting seeds and incoming water transporting seeds and plant fragments. Some types, including curlyleaf pondweed, Eurasian watermilfoil, and coontail, can colonize extensive shallow-water areas. The best way to restrict their growth is to make sure ponds contain adequate depths, as outlined on page 12. Although it is best to transplant locally acquired plants, some can also be purchased. Contact your area Commission fisheries personnel for a listing of aquatic vegetation dealers.



Some of the natural effects of aging and subsequent habitat loss can also be counteracted with water level manipulation. The water level of ponds with gated draw-down valves can be lowered 2 to 3 feet, provided adequate depth remains to prevent a summer fish kill, and maintained at the lower level for an extended period of time. Grasses and broadleaf plants will sprout naturally on the exposed pond bottom, or exposed areas can be seeded with sorghum or Japanese millet. Draw-down can commence in late spring. Hand seeding should be done when mud flats are initially exposed and still moist. The pond should be refilled to flood the established vegetation, either in the fall if a



winter fish kill is possible or the following spring. Although pumps can be used to partially drain and refill ponds for water level manipulation, pumping costs can be considerable.

Water level manipulation can also be used to enhance emergents, with dewatering starting about mid-May and a slow, refilling process starting in September. It also crowds fish, which can make small bluegills more susceptible to predators. Water level manipulations should ideally be done every 4 to 5 years.

Artificial Habitat

A pond owner can install underwater structures, commonly referred to as artificial habitat, to enhance habitat available for numerous aquatic organisms. Research has shown that structures made of natural materials, such as brush and trees, are the most economical and effective types. Rocks, boat docks, wooden pallets, drain tiles, and piles of concrete blocks or bricks can all function as structure.

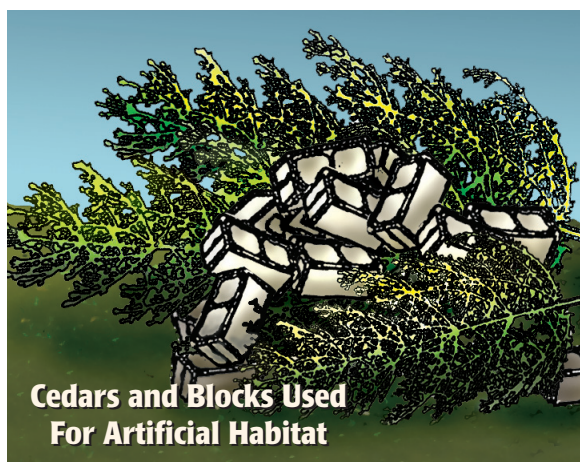
The easiest time to install structures is while the pond is being built. They can be built quickly by pushing downed trees together with a bulldozer and then anchoring them in place. Timber left standing in the pond basin creates natural structure that is very attractive to fish. Most small trees and brush will decompose in a relatively short period of time and will need to be replaced, but hardwoods, cedars, and large trees can last for decades. Trees can be tied together



in various configurations or anchored separately with concrete blocks. Trees can also be kept in place by cabling them to existing stumps or steel posts driven into the pond bottom, as long as there is no concern about the posts causing the pond to leak or becoming a boating hazard.

Although any type of tree will work as habitat structure, hardwoods, osage orange, and especially red cedar, work best. Christmas trees can be used; however, they decompose rapidly and last only a few years. Large pines should be avoided because of their acidity. Plastic banding, polypropylene rope, or heavy, non-corrosive wire can be used to attach anchors directly to trees. Shoreline structure can be made by felling trees along the edge of the pond into the water. To keep these trees in place, cable them to the stump. Or half cut them, leaving a portion of the top connected to the stump.

Artificial habitat can also be added after the pond fills to intentionally attract and concentrate fish for anglers. The best locations for attractors are near natural gathering places for fish and in areas accessible to anglers. Good locations are off points, at the edges of drop-offs, in the mouths of coves, and near boat docks and fishing piers. The structures can be built on the ice during the winter over 4 to 10 feet of water or, if possible, the pond can be partially drained and the structures placed on the exposed bottom. Structures can also be built on the bank and pulled out into the water or hauled in a boat to the ideal fishing spot.



Structures placed in 5 to 10 feet of water can be used by fish year-round. Structures placed in water deeper than 10 feet may not be used during summer months if there is insufficient



Before adding any structure into any surface waters of the state, you must first obtain a Section 404 Permit from the ACOE (see Appendix A for technical assistance contacts).

oxygen at those depths. Good attractors will be about 10 by 15 feet, or larger. Trees can be grouped together in several large piles, which is more effective than spreading individual trees across the entire pond bottom. A good rule of thumb for ponds larger than 5 acres is to build one large brush pile for every 2 to 3 acres of water. For safety's sake, do not place any structures in swimming or wading areas or within 100 feet of spillways or overflow pipes.

Spawning Habitat

Bass and bluegill are typically generalists, thereby eliminating the need to add spawning substrate such as sand or gravel. Some studies have shown bass prefer to spawn near a downed log, or similar structure, when available. There is the likelihood that excessive amounts of sediment in the older ponds can smother eggs in a nest if it is stirred up and then resettles. If an older pond can be partially drained, the exposed pond bottom will then dry out and become somewhat firm, making it better for nest builders. Or, once the pond bottom is exposed, equipment can be used to remove accumulated sediment in several areas. The operation of heavy equipment will also compact the bottom.

Channel catfish usually nest in a cavity. This can be a trash barrel on its side, a large piece of PVC pipe with one end plugged, or any other object that creates a "cave" the fish can lay in and defend. They will also nest alongside protective structure if no cavity is available.



However, there will be limited survival of young catfish if the water is clear and bass are present.

Shallow-Water Habitat

If a pond owner desires, habitat can be further diversified by creating additional shallow-water areas. A small wetland area might be constructed below the dam, or a small pond can be placed above the main pond to provide sediment detention and additional habitat. Perhaps additional shallow-water areas can also be created in the upper reaches of the pond. All of these areas will eventually become vegetated and provide habitat for waterfowl, bullfrogs, and other wildlife.

Fish Feeding

Feeding may be appropriate if the owner is willing to spend the time and money required to produce rapidly-growing, large-bodied bluegills, catfish, wipers, hybrid sunfish, or trout. However, fish must learn to eat commercial food pellets. Pellets should be provided at the same time and location each day. This can be easily accomplished with an automatic, timer-controlled, fish feeder placed on shore or on floats and anchored in the pond. Feeding only when you feel like it is usually a waste of time and money as most fish will never learn to eat the pellets, especially if there is no signal to indicate food is being provided. Fish will learn to react to signals, such as the whirr of the feeder as it turns on, or can be trained to come and eat dispersed pellets by banging on a pipe or post that has been driven into the nearby bank.



Nebraska ponds are usually fertile enough that fish feeding is not necessary.

Artificial feeding can increase the biomass of a pond beyond its normal carrying capacity. If a feeding program is discontinued, the pond may not be able to maintain the extra fish biomass, resulting in poor fish health and growth. Also,

the accumulation of nutrients from uneaten pellets and the increased waste output by artificially fed fish may age a pond quickly, consume oxygen, and stimulate algae blooms. When the algae die, their decomposition can lower dissolved oxygen levels, stressing or killing fish during the night or following several hot, calm, overcast days. When this occurs, fish can be seen at the surface gasping for oxygen early in the morning. An aeration system will help reduce the likelihood of fish kills due to low oxygen levels.



If a pond owner insists on feeding fish, bluegills and/or hybrid sunfish should be provided about 5 pounds of pellets per acre, per day. Make sure the pellets are small enough for them to eat. Largemouth bass do not normally eat commercial pellets because they prefer to eat live aquatic organisms, but they may benefit from increased bluegill production. To increase bluegill and hybrid sunfish growth rates and produce large fish with feeding, there still has to be adequate bass predation on small bluegills and hybrids, unless the owner is willing to spend a fortune on food.

Channel catfish and wipers are practical to feed and quickly learn to eat pellets, resulting in increased growth rates. When catfish and wipers are present in relatively high numbers in multi-species ponds, they may consume the

majority of the pellets, leaving little for other fish. Trout also readily accept dry pellets, and can be grown to larger sizes.

The amount and size of pellets to feed will depend on the fish species present, relative numbers and size range of target fish species, and the time of year. The following guidelines will help improve the success of a feeding program:

- Do not feed more than the fish will consume in 10 minutes. Keep in mind fish must first learn to come to the pellets, so start out with a small amount.
- If fish stop eating, stop feeding and check for low dissolved oxygen levels in the water, diseases, spoiled pellets, or other problems. Consumption of spoiled pellets can stress or even kill fish.
- Stop feeding catfish, wipers, bluegills, and hybrid sunfish when water temperatures are above 90 degrees or below 60 degrees. Stop feeding trout when water temperatures are above 70 degrees or below 50 degrees. Reduce the amount fed as water temperatures approach these temperatures.
- Do not feed after sunset or before sunrise.
- Feed only once and at the same time each day – preferably in the morning.
- Check automatic feeders periodically to make sure they are operating properly.
- Use floating pellets so you are able to observe fish while they are feeding and evaluate their health.
- Consider using a floating hoop to confine the pellets, which will prevent them from drifting to the bank.
- Only use pellets formulated for fish.
- Do not use old pellets – check the packaging date. Nutrient benefits decrease with time. Discard pellets if more than 6 months old.



- Store pellets indoors with room temperatures preferably under 75 degrees.

Contact a local livestock supply store for a source for commercial fish food.

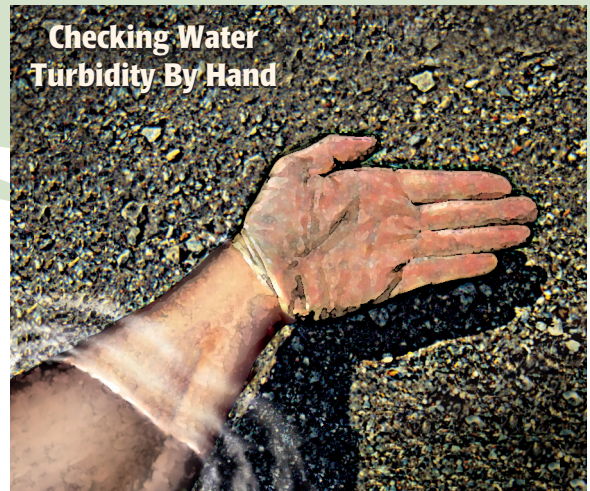
Pond Fertility

Water fertility determines a pond's productivity. A more productive pond will support more fish and a larger harvest than a less productive pond. A pond is considered about right for good fish production if you can see your



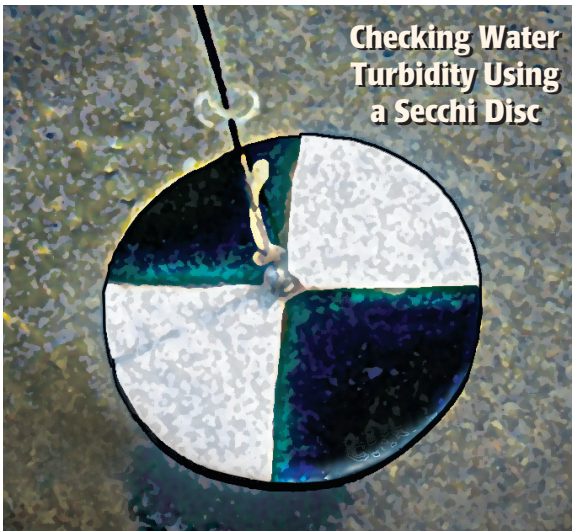
In general, fertilization is not needed in most Nebraska ponds, and adding agricultural fertilizer is prohibited.

fingers when you extend your arm 18 inches downward into the water while in direct sunlight or when a secchi disc is impossible to see at 18 to 24 inches below the pond surface. The level of visibility should be due to the density of existing fish food organisms (such as zooplankton, phytoplankton and aquatic insects), not suspended soil particles. Keep in mind most soils and pond water supplies in Nebraska are nutrient rich; therefore, adding more nutrients to ponds is typically not necessary. Exceptions could be newly created ponds. In Chapter 1,



Checking Water Turbidity By Hand

we discussed the various benefits of placing removed organic-enriched topsoil, brush and trees back in the pond and establishing a cover crop in the basin, when construction was completed. One ensuing benefit was the likelihood of creating a nutrient boost that facilitates initial establishment and expansion of the aforementioned fish food items. With this in mind, the addition of agricultural fertilizer to increase fertility is not necessary and is actually prohibited since it would violate Title 117 Water Quality Standards set by the Nebraska Department of Environmental Quality. Also, if nutrients become excessive, there is the likelihood of excessive aquatic vegetation growth, especially algae, that could negatively impact fish populations.



Checking Water Turbidity Using a Secchi Disc

Terrestrial Habitat

Although fish production is the primary interest for most pond owners, the impounded water will provide habitat for a multitude of organisms, ranging from aquatic insects to terrestrial wildlife. We have already discussed planting areas in and immediately around the pond to control erosion and sediment; however, the vegetative cover near the pond also greatly influences the types of wildlife that will regularly use the pond.

The basic needs of most upland wildlife species are simple: food and cover. Buffer strips





**Fenced Buffer
Around Pond**

adjacent to ponds become important habitat that provide both. Cover is needed for nesting or denning, escape from predators, and shelter from harsh weather. The lack of any of these may limit populations. This cover can also improve water quality and lengthen the life expectancy of a pond by entrapping sediment from erosion on land surrounding the pond.



A pond is a community of many living organisms, with most of them depending on each other for survival. A pond forms a connecting link between the aquatic and terrestrial worlds.

In open rangeland and small pastures, fencing should be used to protect at least a 100-foot wide grassed buffer around the pond. A strip of this width provides excellent habitat, particularly for small mammals and ground-nesting birds, and makes it more difficult for

predators to locate prey. If the pond is to be located in or near cropland or over-grazed pasture, a mixture of native grass and legumes, such as alfalfa and clover, should be planted within the 100-foot wide fenced buffer. Depending on the amount of land available, trees and shrubs can also be considered. Establishing windbreaks near the south and west sides of the pond will provide cover for a variety of wildlife and help to reduce wave action and turbidity. These various plantings will provide winter and escape cover, food production, and nesting areas for wildlife.



It is necessary to periodically set back plant succession to yield greater wildlife benefits and diversity.

The grassed buffer areas need to be periodically manipulated to produce a wide diversity of grasses and broadleaf plants, also known as forbs, that can be utilized as food and cover for the various kinds of wildlife desired. Wildlife utilization of a habitat can then be increased by maintaining a stage of plant succession. Since vegetation cannot be held at a particular stage for any great length of time, it becomes necessary to set back succession and allow the process to start over; thus, recycling the most beneficial successional stages. This can be accomplished by controlled burning, mowing, lightly discing and interseeding with legumes or forbs, grazing, or even careful use of chemicals. These practices, when done correctly, do not destroy the grass, but improve plant diversity and maintain vigorous growth within the stand, yielding greater wildlife benefits and diversity. Other wildlife requirements can also be met if there is a need to plant additional trees and shrubs. Contact your area Commission wildlife biologist or the NRCS about habitat planning and periodic manipulation.

Waterfowl Production

Most pond owners enjoy seeing waterfowl use their ponds and most ponds can be



2021 NCF-Envirothon Nebraska Aquatic Ecology Study Resources

Key Topic #4: Watersheds and the Hydrologic Cycle

12. Describe how water moves through a watershed and its effect on water quality.
13. Diagram the hydrologic cycle and explain how different types of land use affect the aspects of this cycle.
14. Identify different types of aquatic sampling equipment and describe how these tools are used to collect physical and biological data.
15. Identify the major ecoregions and aquatic habitats across the state of Nebraska, and describe their characteristics.

Study Resources

Introduction to Watersheds – *University of Nebraska – Lincoln, 2021* (Page 81)

Movement of Water – *Math/Science Nucleus, 2021* (Page 82 – 84)

The Hydrologic Cycle – *National Aeronautics and Space Administration, United States, 2021* (Pages 85 – 86)

Ekman Dredge – *University of Minnesota, 2021* (Page 87)

The Secchi Dip-In – *The North American Lake Management Society, 2021* (Page 88)

Standard Benthic Macroinvertebrate Sampling Gear Types for Streams - *Environmental Protection Agency, 2021* (Page 89 - 90)

Ecoregions of Nebraska and Kansas – *Chapman, Shannen S., Omernik, James M., Freeouf, Jerry A., Huggins, Donald G., McCauley, James R., Freeman, Craig C., Steinauer, Gerry, Angelo, Robert T., and Schlepp, Richard L. - Collaboration by US EPA, USFS, USDA NRCS, USGS, Nebraska DEQ, Nebraska Game and Parks Commission, Kansas Biological Survey, Kansas Geological Survey, Kansas Department of Health and Environment, and Kansas Wildlife and Parks; 2001* (Separate document)

Study Resources begin on the next page!



Introduction to Watersheds

University of Nebraska – Lincoln, 2021



Everyone lives in a watershed. A watershed is the land area that contributes water to a location, usually a stream, pond, lake or river. Everything that we do on the surface of our watershed impacts the water quality of our streams, wetlands, ponds, lakes and rivers. What happens in one locality affects other downstream areas.

Protecting our water resources requires looking at water quality issues from a watershed perspective. [Watershed planning and management](#) consists of coordinated activities aimed at controlling, enhancing or restoring watershed functions.

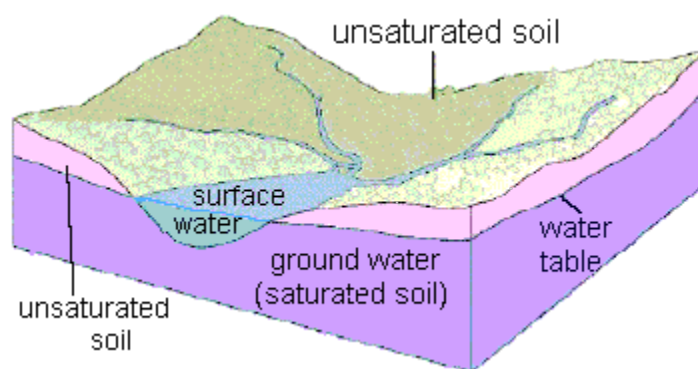
Runoff pollution is the primary source of water quality problems in our [lakes, ponds and streams](#). It can come from many different sources in a watershed. [Water quality protection practices](#), or best management practices (BMPs), are systems, activities and structures that are constructed or practiced to prevent [runoff pollution](#).

Impaired lakes, streams and rivers are a concern throughout the state of Nebraska. Explore how the University of Nebraska-Lincoln conducts research and Extension programming to address watershed issues in several [focused watersheds](#) in the state.

Movement of Water

Math/Science Nucleus, 2021

Surface movement includes rivers, streams, creeks, lakes, ponds, and human-made "flood" control. All surface water is trying to reach sea level due to gravity. As water flows in **channels**, the **streambed** and banks of the channel will resist the flow of water. The velocity of the water is dependent on steepness of the slope, type of rock or soil, amount of vegetation, shape of stream bed, and obstructions. Surface water provides the liquid where most evaporation takes place.



Water movement

Groundwater refers to water that has penetrated the soil or bedrock and moves through rocks that have a high pore space. The water comes from **infiltration** of surface waters including lakes, rivers, recharge ponds, and even waste-water treatment systems. Groundwater is also affected by the force of gravity. However, because of some of the properties of water, it can pool in higher area and actually defy gravity in some cases. The water table is the upper level of the saturated zone of groundwater.

Rivers, streams and creeks are a surface water system with a network of channels that collect and move runoff. **Runoff** is excess water that is not adsorbed by the surrounding area. Runoff can be created by rainfall, melting snow, or groundwater discharge. The shape of the river system will depend on the topography, the type of rock or soil it is traveling through, and the style of its biological diversity.

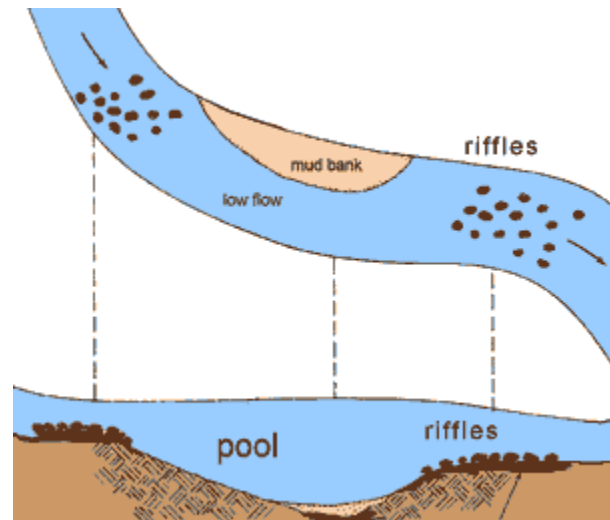
Rivers and streams change depending on the amount of water that flows throughout the year. This relies on a continuous source of water is from the surface or subsurface. A **perennial** flow is a channel that has water all year round. An example would be the great rivers of the world including the Ganges River (India), Amazon River (South America), or the Nile River (Africa). An **intermittent stream** would be a flow that is more than 50% during the year.

An **ephemeral** flow generally refers to a stream or creek that only has water part of the year. This is usually in areas, like deserts, that are dry most of the year, but do have maybe 2 months of rain.

Surface flows will wiggle and wind through the surface landforms. There are many flow types depending on the velocity of the river. If the velocity is high, it tends to cut into bedrock in a

"straight" line. Velocities will be high if there is sufficient relief. When the velocity is low, the stream will tend to **meander** if the rock type and topography permit it.

Water velocity helps to create three basic types of channel patterns, including **braided**, meandering, and straight. There are many patterns that grade into each other. Rivers in a straight pattern do not stay ruler straight for long! The physical properties of water and the area the river is eroding tend to have the deepest part of the river (called the **thalweg**) alternating from side to side on the channel. Erosion of the land starts a physical separation of the pieces. Larger pieces don't move very far and drop out of the system. However, finer grained sediment settles out in quieter area. So water will be attacking one side of the river and the other side will be depositing sediment. Over the years this will create meandering.



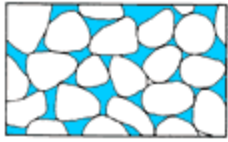
Stream diagram

In many areas where you find braided channels, surface water is just "dumped" into a lower topographic area. The sediment load is large, and the river breaks up into smaller channels with a branching, but braided look.

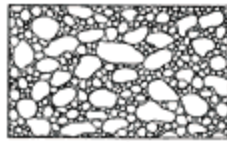
The flow will also dictate how the sediment is deposited, which in turn contributes to the type of **habitat** available to different types of organisms. Three types of bedforms provide excellent "living" space, including mud, **riffles**, and **pools**. The accumulation of fine-grained sediments (mud) in quiet rivers can influence growth for small invertebrates and fish eggs. The mud represents a "cushion", and if disturbed because of increased movement of water, can cause damage to the organisms that live there.

Riffles are relatively shallow portions of a river with a change in elevation where water cascades over cobbles or boulders along its path. The fast-moving water allows gas in the atmosphere to mix with the water, therefore increasing the dissolved oxygen that enters the water system. Behind the rocks are areas that debris can build up and act as a habitat for fly **larvae** and other small invertebrates.

Pools of water are areas that are deeper. When water reaches a pool the velocity of the water slows down, making it an excellent resting place for fish.



A



B



C

Various types of rock sorting that can trap water

and exchange some elements and compounds when they are dissolved in water. This helps to eliminate other pollutants that filtration cannot handle.

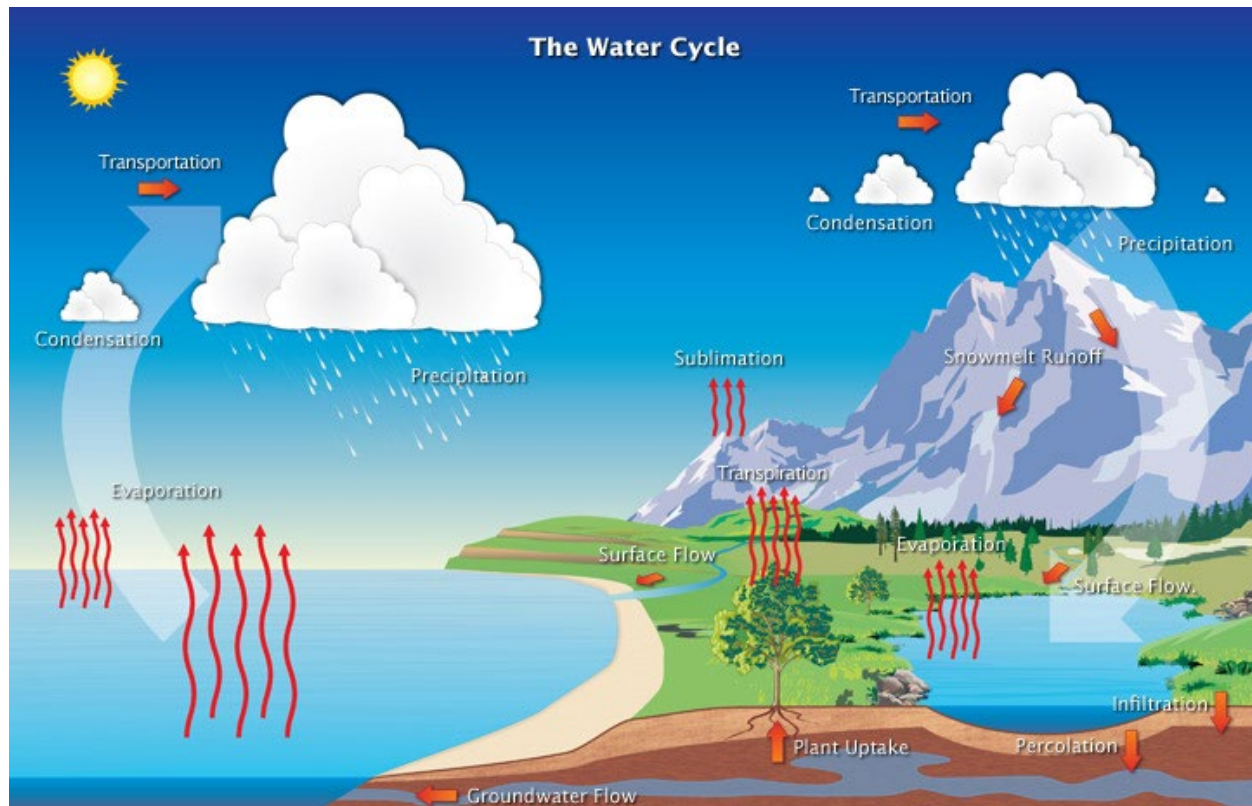
Ground water as it moves through soil and rock is actually being naturally filtered. Some substances like sand can help filter pollutants and particles easily. Clays in soil and rock also act as a way to "capture"

Water is stored in **aquifers**, which have similar characteristics of reservoir rocks that store soil and gas. Well-sorted sediments with high **porosity** (A) and highly **fractured** (C) rocks are excellent candidates for aquifers. If poorly sorted rocks are partially cemented (B), they are not good reservoir rocks. The fluid must have room to move around. An aquifer is not an underground river, it just retains the water until it is pumped out through a well or naturally emerges as a **spring**.

The Hydrologic Cycle

National Aeronautics and Space Administration, United States, 2021

The water, or hydrologic, cycle describes the pilgrimage of water as water molecules make their way from the Earth's surface to the [atmosphere](#) and back again, in some cases to below the surface. This gigantic system, powered by energy from the Sun, is a continuous exchange of moisture between the oceans, the atmosphere, and the land.



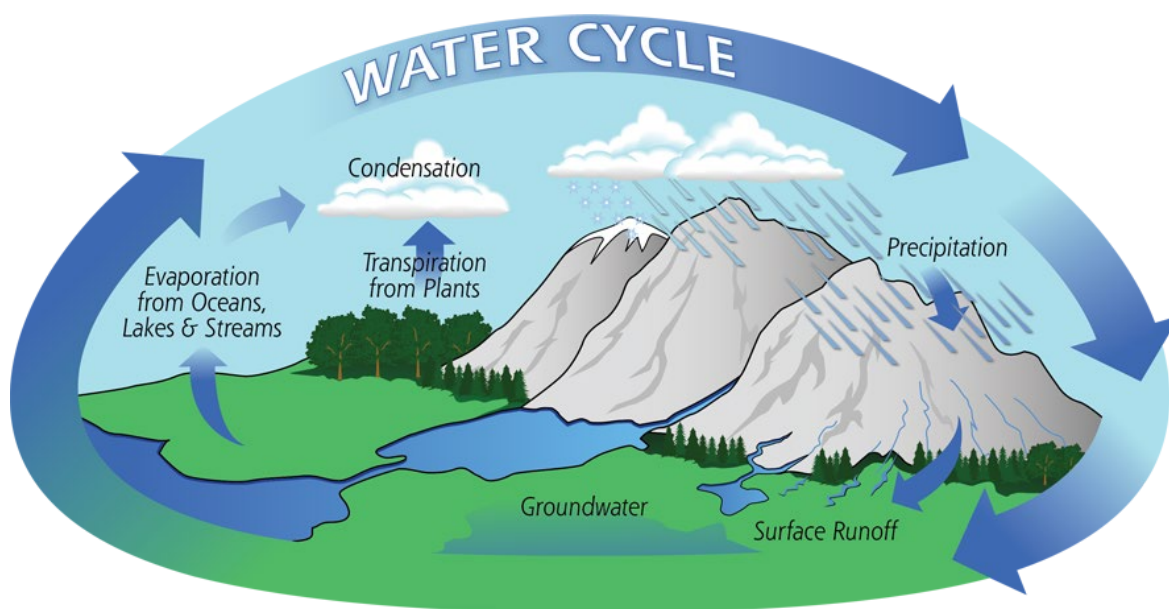
Studies have revealed that evaporation—the process by which water changes from a liquid to a gas—from oceans, seas, and other bodies of water (lakes, rivers, streams) provides nearly 90% of the moisture in our atmosphere. Most of the remaining 10% found in the atmosphere is released by plants through [transpiration](#). Plants take in water through their roots, then release it through small pores on the underside of their leaves. In addition, a very small portion of [water vapor](#) enters the atmosphere through sublimation, the process by which water changes directly from a solid (ice or snow) to a gas. The gradual shrinking of snow banks in cases when the [temperature](#) remains below freezing results from sublimation.

Together, evaporation, transpiration, and sublimation, plus volcanic emissions, account for almost all the water vapor in the atmosphere that isn't inserted through human activities. While evaporation from the oceans is the primary vehicle for driving the surface-to-atmosphere portion

of the hydrologic cycle, transpiration is also significant. For example, a cornfield 1 acre in size can transpire as much as 4,000 gallons of water every day.

After the water enters the lower atmosphere, rising air currents carry it upward, often high into the atmosphere, where the air is cooler. In the cool air, water vapor is more likely to condense from a gas to a liquid to form cloud droplets. Cloud droplets can grow and produce precipitation (including rain, snow, sleet, freezing rain, and [hail](#)), which is the primary mechanism for transporting water from the atmosphere back to the Earth's surface.

When precipitation falls over the land surface, it follows various routes in its subsequent paths. Some of it evaporates, returning to the atmosphere; some seeps into the ground as soil moisture or [groundwater](#); and some runs off into rivers and streams. Almost all of the water eventually flows into the oceans or other bodies of water, where the cycle continues. At different stages of the cycle, some of the water is intercepted by humans or other life forms for drinking, washing, irrigating, and a large variety of other uses.



Precipitation is a vital component of how water moves through Earth's water cycle, connecting the ocean, land, and [atmosphere](#). Knowing where it rains, how much it rains and the character of the falling rain, snow or [hail](#) allows scientists to better understand precipitation's impact on streams, rivers, surface [runoff](#) and [groundwater](#). Frequent and detailed measurements help scientists make models of and determine changes in Earth's water cycle.

The water cycle describes how water evaporates from the surface of the earth, rises into the atmosphere, cools and condenses into rain or snow in clouds, and falls again to the surface as precipitation. The water falling on land collects in rivers and lakes, soil, and [porous](#) layers of rock, and much of it flows back into the oceans, where it will once more evaporate. The cycling of water in and out of the atmosphere is a significant aspect of the [weather](#) patterns on Earth.

Ekman Dredge

University of Minnesota, 2021



Ekman dredges (Ekman, 1911) are metal boxes with side length ~15cm, and a pair of spring-gate doors that are held open during deployment and closed during recovery. The box is lowered into the sediment via rope or wire. The operator slides a messenger down the line, which closes the doors, and the sample is returned to the surface. Recovered sediments are assumed to be mixed.

Type: Grab

Minimum Water Depth (m): 0

Maximum Water Depth (m): limited by wire/rope length

Maximum Sediment Depth (m): 0.2

Dimensions and Weight: 2 kg, 20x20x30cm

Minimum Open-Water Deployment Requirement: canoe/kayak

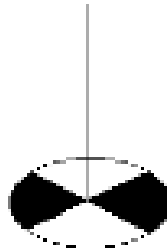
Core Diameter/Profile (cm): 20 x 20 x 30, box

Lithologies: Soft Sediment

The Secchi Dip-In

The North American Lake Management Society, 2021

What is a Secchi Disk?



A Secchi disk is an 8-inch (20 cm) disk with alternating black and white quadrants. It is lowered into the water of a lake until it can no longer be seen by the observer. This depth of disappearance, called the Secchi depth, is a measure of the **transparency** of the water.

Transparency can be affected by the color of the water, algae, and suspended sediments. Transparency decreases as color, suspended sediments, or algal abundance increases. Water is often stained yellow or brown by decaying plant matter. In bogs and some lakes the brown stain can make the water the color of strong tea. Algae are small, green aquatic plants whose abundance is related to the amount of plant nutrients, especially phosphorus and nitrogen. Transparency can therefore be affected by the amount of plant nutrients coming into the lake from sources such as sewage treatment plants, septic tanks, and lawn and agricultural fertilizer. Suspended sediments often come from sources such as resuspension from the lake bottom, construction sites, agricultural fields, and urban storm runoff.

Transparency is an indicator of the impact of human activity on the land surrounding the lake. If transparency is measured through the season and from year to year, trends in transparency may be observed. Transparency can serve as an early warning that activities on the land are having an effect on a lake.

Standard Benthic Macroinvertebrate Sampling Gear Types for Streams

Environmental Protection Agency, 2021

Kick net: Dimensions of net are 1 meter (m) x 1 m attached to 2 poles and functions similarly to a fish kick seine. Is most efficient for sampling cobble substrate (i.e., riffles and runs) where velocity of water will transport dislodged organisms into net. Designed to sample 1 m² of substrate at a time and can be used in any depth from a few centimeters to just below 1m (Note -- Depths of 1m or greater will be difficult to sample with any gear).

D-frame dip net: Dimensions of frame are 0.3 m width and 0.3 m height and shaped as a "D" where frame attaches to long pole. Net is cone or bag-shaped for capture of organisms. Can be used in a variety of habitat types and used as a kick net, or for "jabbing", "dipping", or "sweeping."

Rectangular dip net: Dimensions of frame are 0.5 m width and 0.3 m height and attached to a long pole. Net is cone or bag-shaped. Sampling is conducted similarly to the D-frame.

Surber: Dimensions of frame are 0.3 m x 0.3 m, which is horizontally placed on cobble substrate to delineate a 0.09 m² area. A vertical section of the frame has the net attached and captures the dislodged organisms from the sampling area. Is restricted to depths of less than 0.3 m.

Hess: Dimensions of frame are a metal cylinder approximately 0.5 m in diameter and samples an area 0.8 m². Is an advanced design of the Surber and is intended to prevent escape of organisms and contamination from drift. Is restricted to depths of less than 0.5 m.



Figure 1 – Kick Net



Figure 2 – D-Frame Net



Figure 3 – Rectangular Dip Net



Figure 4 – Surber Sampler



Figure 5 – Hess Sampler