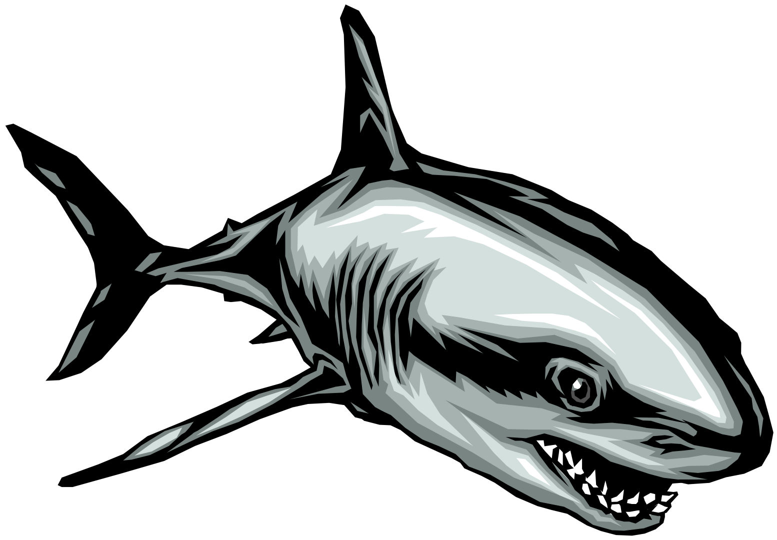
# ADAPTIVE RADIATION AND EVOLUTION: FISHES



**Purpose**

The purpose of this exercise is to illustrate some of the adaptive radiation and subsequent evolution of fishes. We will make direct observations of living fishes at the Stephen Birch Aquarium-museum, located at the Scripps campus of UCSD. We will look at two of the three classes of fishes, the cartilaginous fishes (Chondrichthyes) and the bony fishes (Osteichthyes).

The ocean is a stable place to live. The ocean's temperatures are generally uniform over a long period. Water offers support to fish's bodies, so that strong skeletons are not necessary, although the high viscosity of water creates a problem to their locomotion. The fish’s solution, in response to this problem, is to achieve some degree of streamlining. As a result, fishes from the same habitat look very much alike. It is not that these fishes are closely related because of their similar look, but the solution to the locomotion through the water is a common one.

We will first explore the cartilaginous fishes such as sharks, skates, guitarfishes and rays. We will see how they solved the problem presented by their high body density (heavier than water) and underwent adaptative radiation that lead most of them to the bottom habitat. Next, we will look at the bony fishes. These bony fishes, with their specially evolved "swim bladder" solved their body density problem. This allowed the bony fishes to exploit new environments and niches (occupations) not available to the cartilaginous fishes.

## Locomotion In Water

Fishes swim by special longitudinal muscles that are attached along the spine and branch out diagonally up and back over the lateral surface. Contractions of these special muscles result in a double curve of the body resembling an "S" shape or sine curve. This curve starts at the anterior end of the fish and travels toward the tail. This wave of motion sends water down along the side of the fish resulting in the fish's forward movement.

Some fishes use their body so that the curve is large or has a high "amplitude," especially in fishes lacking paired fins. Their efforts result in a strong sideways movement with little forward movement. Other fishes may create rapid, almost vibrational body movements with little sideways movement, but with great forward movement.

## Swimming in Chondrichthyes

The cartilaginous fish's body is heavier than water. If the shark were to quit swimming, it would sink. The shark's pectoral fins (see **Figure** 2) probably evolved from folds of skin along its body. Note how these pectoral fins are placed low along the sides of the body and are at right angles to its surface.

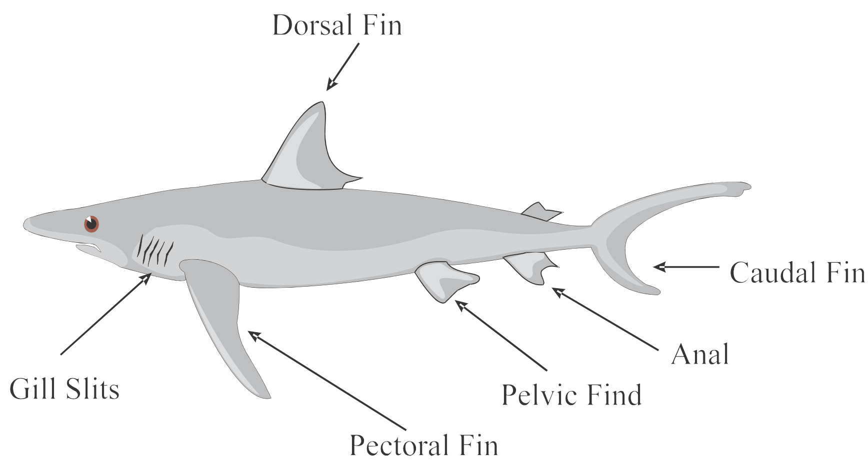



**Figure 2**

*Note the Leopard sharks in the Giant Kelp Tank (K[1] 19) to answer the following questions.*

How flexible are the shark's pectoral fins as compared with a bony fish's pectoral fins?

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Fishes that use their pectoral fins as hydrofoils (water wings) hold their fins rigidly. Those fishes whose pectoral fins are flexible use them to make slight adjustments in body position. How would you describe the shark's use of its pectoral fin in swimming?

______________________________________________________

Notice the asymmetrical design of the shark's caudal fin. The upper lobe of the caudal is much larger than the lower lobe (called a *heterocercal* tail). Movement of this tail shape would tend to drive the shark's head in what direction (up or down)?

________________________________________________

The shark's head shape is flat and angled down from the first dorsal fin to the tip of the snout. How would this head shape affect the shark's locomotion through the water (would move the fish up or down)?

___________________________________________________

Experiments on sharks have demonstrated that when the pelvic fins (see Fig 2) were removed, the shark's swimming was unaffected. We may conclude then that the primary function of the pelvic fins is not for swimming. The shark does have an important function for these fins, namely reproduction. Male cartilaginous fishes have evolved an insemination device called a *clasper*. This structure enables the males to fertilize the females internally. Examine the sharks, rays, skates or guitarfishes on display.

Describe the shape of the clasper and from which paired fin it evolved.

________________________________________________________

**Flattened Chondrichthyes**

The evolution of the Chondrichthyes is directed by their high body density compared to the density of water. Most cartilaginous fishes have given up fighting the problem of staying up in the water column and have settled down to the sea floor. Thus skates, rays and guitarfishes (see Figure 3) represent the evolutionary solution to this sinking problem.

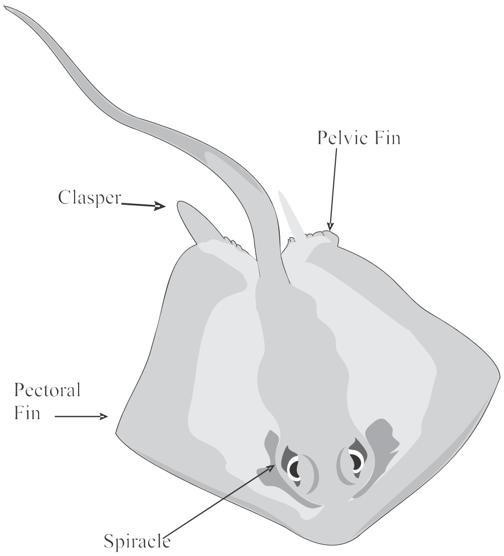


Figure 3. Flattened Cartilaginous Fish

What kind of ocean habitat (open water, surface, or bottom) did the flattened cartilaginous fishes evolve to?

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The body shape is similar in these flattened cartilaginous fishes in that they are flattened in what direction (side to side or top to bottom)?

___________________________________________________________

Which fins are used by the flattened cartilaginous fishes to swim (observe the Stingray)?

___________________________________________________________

The Guitarfish is atypical of the flattened cartilaginous fishes in how it swims. How is the Guitarfish different?

___________________________________________________________________________

Sharks take in water through their mouth and then blow it out over their gills through the gill slits. The large hole (spiracle) just behind the eye is considerably larger in the flattened cartilaginous fishes than in the non flattened sharks. Noting that the flattened cartilaginous fishes have their mouth in the sand.

Why do the flattened cartilaginous fishes have a large spiracle?

______________________________________________________________

What has happened to the size and importance of the caudal, dorsal and anal fins in the flattened cartilaginous fishes as compared with the non flattened sharks?

______________________________________________________________

Compare a free-swimming shark with a free-swimming bony fish by completing Table 17-1.

Table 17-1

| Characteristic | | Shark (K-19) | Bony Fish (Black Sea Bass K-19) |
|---|---|---|---|
| Pectoral Fin | Relative size to body (large or small) | | |
| | Position Fin Inserted on Body (Lateral or Ventral) | | |
| | Flexibility | | |
| | Main Function | | |
| Pelvic Fin | Relative Size | | |
| | Location on Body | | |
| | Primary Function | | |
| Caudal Fin Shape (Symmetrical or Asymmetrical) | | | |
| Behaviors | Actively swimming | | |
| | Hovering (Stationary in water) | | |
| | Resting on Bottom | | |

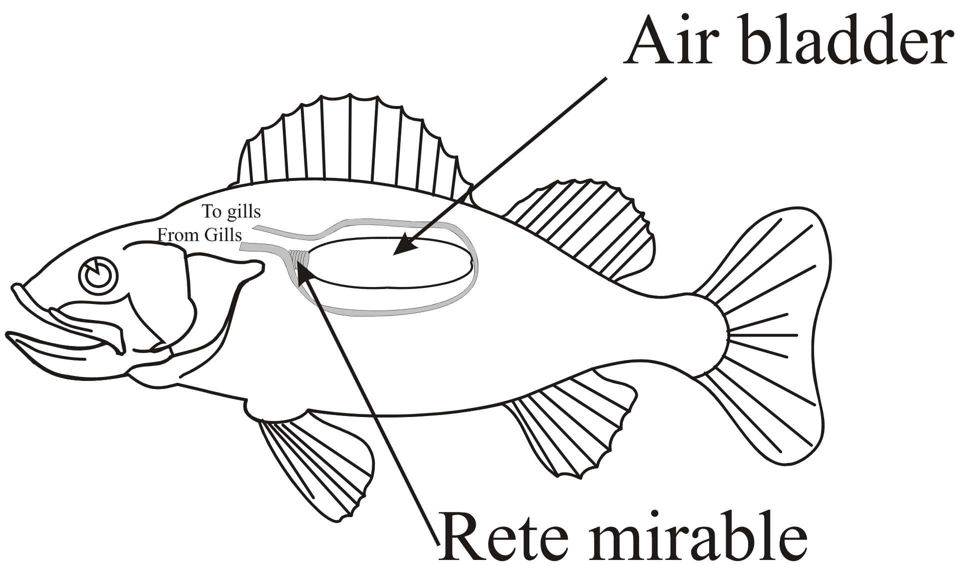

Figure 4.  Air Bladder

## LOCOMOTION IN THE BONY FISHES

One key to success in the bony fishes is the presence of a swim bladder. This is a gas-filled sac, located dorsally within the body cavity. This sac, originally evolved as an air bladder or accessary lung, was connected directly to the esophagus. Although some fishes still have the swim bladder
connected to the digestive tract, in most modern fishes the swim bladder is a separate organ. The fishes can adjust the amount of gas within the bladder to lighten their body weight. The lighter weight makes it easier for the fishes to maintain a specific depth without an excess expenditure of energy. The bony fishes can browse at one spot without sinking, while the shark must continue swimming. Fishes that hold position in the water for some length of time have a swim bladder, whereas those bony fishes that are fast moving, streamlined and pelagic often lack air bladders. Watch the activity of bony fishes in the tanks. Note which fishes keep moving all the time, never stopping or if they stop, do they sink? Note which bony fishes can stop in the middle of the water column for some length of time. Give some likely examples of each type in Table 2.

Table 2. Comparison of bony fishes with and without air bladders.

| Air Bladder | Bony Fish Example |
| --- | --- |
| Well Developed | |
| Probably Lacks | |

**Body Form**

An evaluation of a fish's body form will allow the viewer to gain an insight into its way of life. The body form is determined by observing the fish's frontal cross section and comparing it with the fish's side profile. Review the diagram on body form and match the body types with the fishes on page 8.

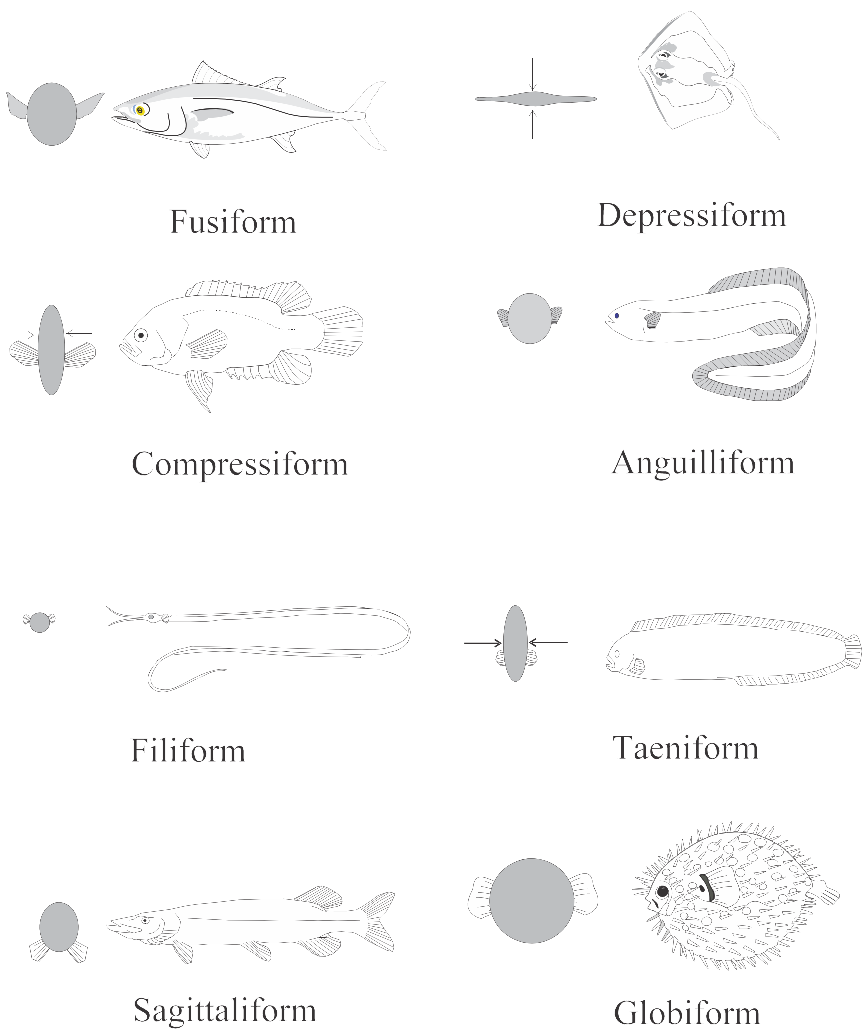


Figure 5 Fish Body Types

Observe the following fishes and record the body type (using Figure 5) and their habitat selection (noting the habitat of the tank) in the table 3.

Table 3. Comparison of body types and habitats.

| Fish | Body Type | Habitat |
|---|---|---|
| Garibaldi | | |
| Pacific Amber Jack | | Open Water |
| Porcupine Pufferfish | | |
| (Any) Ray | | Sandy Bottom |
| Moray Eel | | |

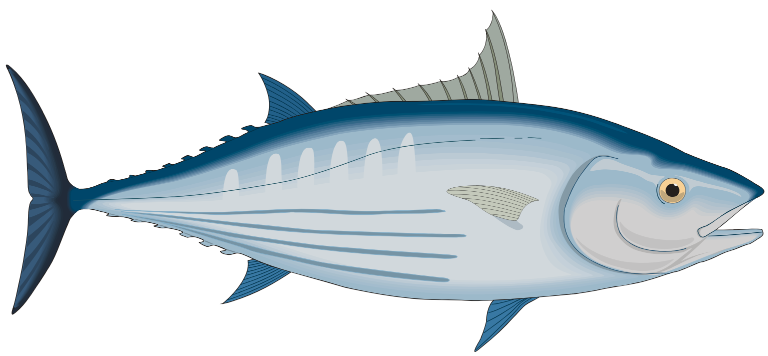

Figure 6. Terminal Mouth

**Mouth Position**

The position of the mouth opening is another concession to the life habits of the fish. Seeing how the mouth opens will give you an idea of where the fish feeds within the habitat in relationship to body position. In other words, does the fish feed above itself, below or straight ahead of its body. Three general types of mouth positions are recognized. An *inferior* mouth opens downward with the lower jaw shorter than upper jaw. A *terminal* mouth opens forward with both jaws being equal in length. The *superior* mouth opens upward with the lower jaw being longer than the upper jaw. Determine the jaw position of the following fishes and record in table 4.

Table 4 . Comparison of a Fish's mouth position and its habitat, using Figure 6 use the terms introduced on page 8.

| Fish | Mouth Position | Habitat |
|---|---|---|
| (Any) Ray | | |
| Sheephead | | |
| Halibut/Flounder | | |

**The Dorsal and Anal Fins - The Medial Fins**

The original function of these fins was to prevent lateral slipping through the water (lateral stabilization). Secondary functions include braking, turning, swimming, luring (prey), holding on (sucker-like), display (antagonism or mating) and in the case of live bearing fishes (eggs hatch in female), the males have a modified anal ray (*gonopodium*) used for insemination.

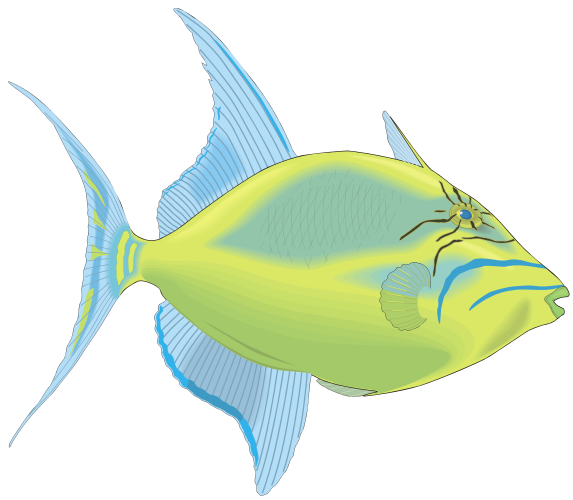

Figure 7. Queen Triggerfish

The size, shape and length of the dorsal or anal fins will be an aid to determine their functions. Long, continuous soft-rayed dorsal and anal fins may be used for locomotion and shorter flexible dorsal and anal fins are used just for stabilization.
Determine how the following fishes use their dorsal and anal fins in Table 17-5.

Table 5. How fishes use their dorsal or anal fin.

| Fish | Function of Dorsal or Anal Fin |
|---|---|
| Pufferfish | |
| Triggerfish or Black Durgon | |

**Pectoral and Pelvic Fins - The Paired Fins**

With the development of the swim bladder in bony fishes, the paired fins no longer must serve as hydrofoils as in sharks. Slow moving to stationary life habits from midwater to surface waters become available to the now neutrally buoyant bony fishes. The paired fins were now free to evolve and adapt the bony fishes to these new life habits.

Pectoral fins moved from a low ventral position on the body to a more lateral position high on the body. The size and shape of the pectoral fins vary from large wing-like pectorals for aerial gliding (flying fish) to thick rounded pectorals for resting on rocks and climbing.

Pelvic fins in most bony fishes moved through evolution from an abdominal position (on the belly) to a thoracic position just under the throat. Their functions vary from creating drag to being sucker-like. Some bottom dwelling, snake-like fishes may even lack paired fins.

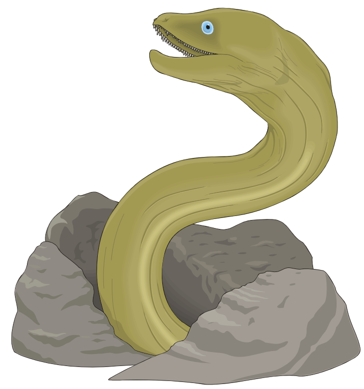

Figure 8. Moray Eel

The following fishes show some modification of their pectoral or pelvic fins, indicate in Table 6, which fin is modified and probable function.

Table 6. How fishes use their paired fins.

| Fish | Paired Fin Function |
|---|---|
| Lionfish | |
| (Any) Rockfish | |
| Rainbow Wrasse | |
| Moray Eel | |

**Caudal Fin -The Tail Fin**

The caudal fin is important in increasing the forward thrust while reducing the amplitude of the lateral movement of the fish's body. The shape of the tail, rigidity of its elements and the thickness of the caudal peduncle (where the tail bends) all serves the fish in its locomotion. Caudal fin shapes vary with the streamlined thin crescent shaped tail fins of the speedster fishes through forked shaped fins to truncated (squared off) shaped fins of the slower moving fishes. Compare the caudal fin of an efficient swimmer such as the Yellowtail Tuna, Jack, with a slower moving fish such as a Grouper or Sea Bass in Table 7.

Table 7. Comparison of the caudal fin of a slow moving fish with a fast moving fish.

| Fish | Shape of Caudal | Rigidity of Caudal Fin | Thickness of Caudal Peduncle |
|---|---|---|---|
| Fast Swimmer (Such as a Jack) | | | |
| Slow Swimmer (Such as a Grouper) | | | |

In the slower moving fish, how was the tail held when the fish was not moving as compared to actively moving?

______________________________________________________________________

## COLORATION IN FISHES

The fish's coloration will either serve to disguise it in its habitat or serve to announce its' niche in the environment. There are three general coloration types in fishes: cryptic, countershaded and bold.

### Cryptic Coloration

Cryptic means "hidden" and is literally the function of this type of coloration. This is achieved in one of two general ways: (1) *assimilation* with the background; (2) body outline *disruption*. Assimilation involves a general mottling or banding of the entire lateral surface, blending the fish into its surroundings. Body disruption involves bands or stripes that break up the fishes shape from the side into uneven blocks, thus disguising its actual shape.

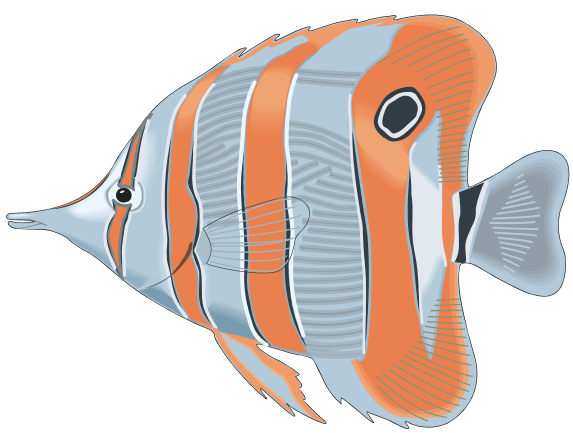

Figure 9

Determine the type of cryptic coloration of the following two fishes in Table 8.

Table 8. Comparison of assimilative and disruptive coloration.

| Fish | Assimilation or Disruptive |
|---|---|
| Scorpionfish | |
| Spadefish | |

One cryptic strategy used by many fishes is to hide their eye within an eye stripe. This does two things: (1) the shape and location of the eye is disguised and (2) a confusion boundary or double outline is presented to the potential predator. See Figure 9.

**Eye Shape**

Living organisms have definite shapes. The most difficult shape to hide is the eye shape, unless the eye is made part of the body pattern. Some fishes have a conspicuous false "eye" located near the tail. Predators generally would go after prey by predicting which way the fish will swim.

What advantage would it be to a fish to have a false "eye" spot?

____________________________________________________

**Body Outline**

Another obvious feature that would give the fish's position away, is its body outline. The body outline is difficult to hide especially from the side view. A confusion boundary stripe has been evolved to add to the predator's confusion as to where the actual fish's body outline lies. Examine fishes with either vertical or horizontal eye stripes and fill in Table 9. Suggest that you might look at any of the following: Cortez Angelfish, Spadefish, or Butterfly Fish,. Sailfin Surgeonfish, Shrimpfish, Rainbow Basslet and the Five-lined Cardinal Fish.

Table 9.Comparison of body shape and stripe direction.

| Fish | Stripe Direction |
|---|---|
| Short-Wide Fish | |
| Long-Narrow Fish | |

**Countershading**

Another strategy used by fishes is that of countershading. The fish's upper surface is striped dark green or blue, while the underside is silver or white. The dorsal striping gives the appearance of disturbed water, the light underside helps to eliminate shadows and blends the fish's belly into surface reflections. This of course only works for upper water fishes.

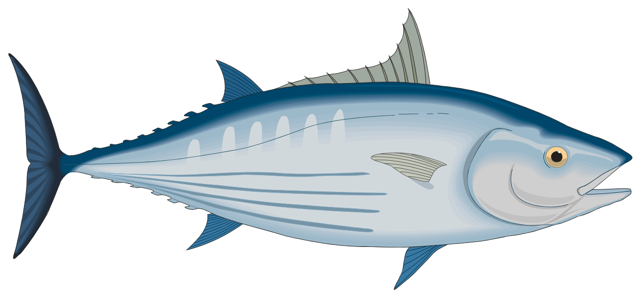

Figure 10. Countershaded Fish.

Give an example of a countershaded bony fish.

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Give that shallow water is green at the surface and deep water is blue, is there a relationship between the fish's dorsal color (green or blue) with the fish's habitat for near shore water verus off shore water? What is the association?

______________________________________________________________

**Bold Coloration**

Some fishes stand out from their surroundings. These fishes are brightly colored or boldly colored fishes. This seems contradictory to the idea that fishes would not want to be seen. There are four general reasons why a fish would have bold coloration.

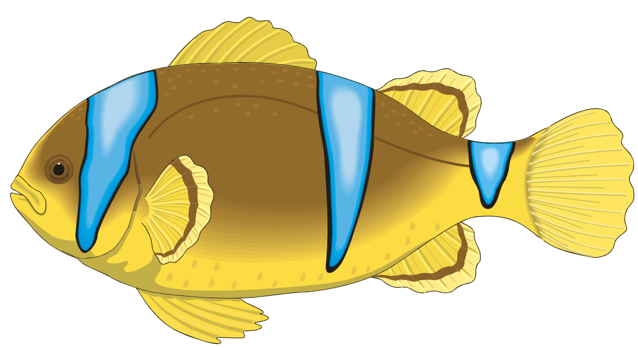

Figure 11 Clownfish

*Signal* or warning coloration that may signal either an aggressive behavior or bad taste (poisonous) may result. Garibaldi are well known for the aggressive behavior and fishes soon learn to avoid those reddish fishes.

*Sexual dimorphism* may announce territories to other males or sexual maturity to the opposite sex. Note that many of the Wrasses (i.e. Sheephead) go through sex reversal, starting off female and turning into males. As they go through the change, their color and body shape often changes.

*Schooling stripe* is a midlateral dark stripe that aids schooling species to maintain visual contact with each other. This usually seen in small schooling fishes such as anchovies, sardines, and topsmelt.

*Cleaner fish* species have brightly colored bodies and often distinctive behavior to announce their parasite picking activities to potential customers. Many of the Wrasses such as Rainbow Wrasse, Señorita are cleaner fishes.

Observe the following boldly colored fishes and determine their color's probable function and fill out Table 10. Note the graphics on the wall opposite the aquaria for more information.

Table 10. Comparison of bold coloration with their functions.

| Fish | Function of Bold Coloration |
|---|---|
| Garibaldi | |
| Rainbow Wrasse | |
| Male Sheephead | |

12 Male Sheephead

SUMMARY QUESTIONS

Which kind of fishes (bony or cartilaginous) are heavier than water?

______________________________________________________________________

Which general body form has evolved in the cartilaginous fishes?

_____________________________________________________________________

The emphasis of swimming with the caudal fin in the sharks has shifted to what fin in skates and rays?

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In the bony fishes, the mouth positions can be any one of the three types. In the cartilaginous fishes the mouth position is only:

______________________________________________________________

What important structure in the bony fishes gives them greater success in their adaptive radiation?

______________________________________________________________

What coloration type(s) is (are) not seen in the cartilaginous fishes?

____________________________________________________________________

The following represents a key to the tank location and habitats at the Stephen Birch Aquarium. The next page has a diagram of the aquarium. Map and keys are taken from the Stephen Birch Aquarium information sheets.

**Entrance**

1. Sardines

**Northwest Coast** (**NW**)

2. Rocky Pinnacle
3. Offshore Reef
4. Protected Coast
5. Giant Octopus

**Southern California** (**SC**)

6. Shark Egg Case
7. Off Shore Depths
8. Open Ocean
9. Open Ocean
10. Coastal Lagoon
11. Shallow Bay
12. Rocky Reef
13. Rocky Reef
14. Pier Piling
15. Near Shore Rocky Reef
16. Submarine Canyon
17. Submarine Canyon
18. Rocky Reef

**Kelp Forest** (**K**)

19. Giant Kelp Forest

**Mexico** (**M**)

20. Bahia Magdalena
21. Cabo San Lucas
22. Los Islotes A Rocky Reef
23. Los Islotes A Rocky Bottom
24. Los Islotes A Deep Rock Reef
25. Isla Ballena

**Tropical Seas** (**TS**)

26. Socorro Island
27. Lagoon
28. Back Reef
29. Fore Reef
30. Caves and Crevices
31. Lagoon
32. Deep Reef
33. Deep Reef