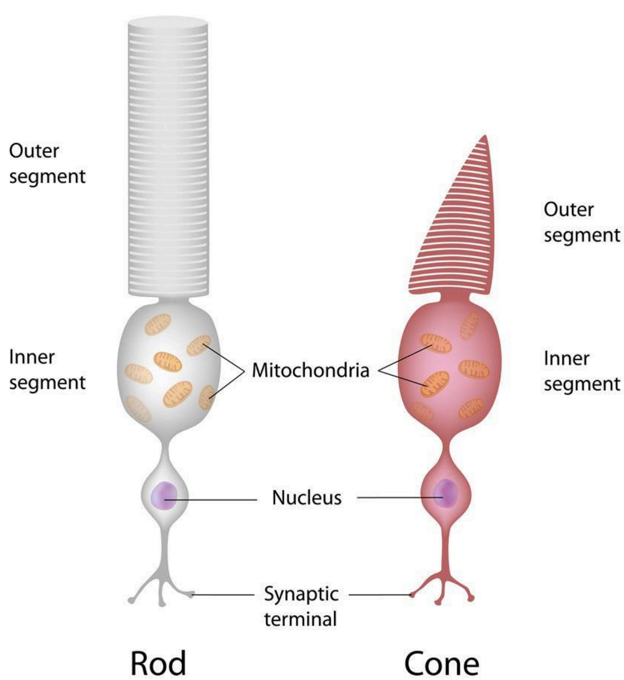
The Amazing Eye of the Trout, Part 2

By Beth Jappay

Trout are visual hunters, and in adapting to an underwater environment they have come with ways of focusing light and dealing with varying light levels that are very different from the solutions mammals have come up with. Understanding these differences will allow us to better target them.

In last month's article we discussed how the trout eye is simultaneously near-sighted for objects ahead and far-sighted for objects that are to the side and behind, and how this adaptation improves survival. This month we will explore how the trout eye differs from ours in seeing color and adapting to changing levels of light, a topic with a big impact on fly pattern and color selection. Trout are excellent night hunters, yet do not have eyelids or an iris to protect their sensitive eyes from bright daylight. Their adaptation involves varying the shape of their light-sensing rods and cones from day to night and greatly affects the color of fly most visible to them.

Rods and night vision



Rods are responsible for night vision in both mammals and fish. They are taller than cones because they have stacked their light-sensing units higher, making them more sensitive to small amounts of light. In fact, rods are 30-100 times more sensitive to light than cones and may even react to a single photon. Rods respond to light in the blue-green spectrum and do not respond to light in the red spectrum. Therefore using a red light won't affect night vision (or spook trout when night fishing).

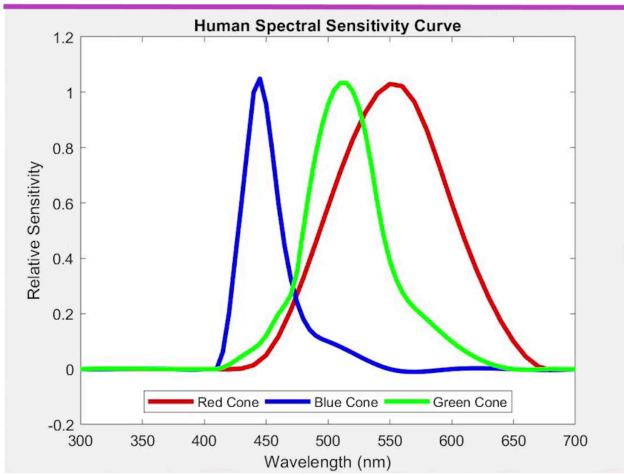
Think of rods as night-vision goggles–monochromatic, coarse, but projecting sharp contrast. Rods contribute less to visual acuity because they react very slowly to changes in light levels, and because they gang up together in larger groups to send a single signal to the brain. Fish rely on rods for most of their lateral and monocular vision.

Cones and color/acuity

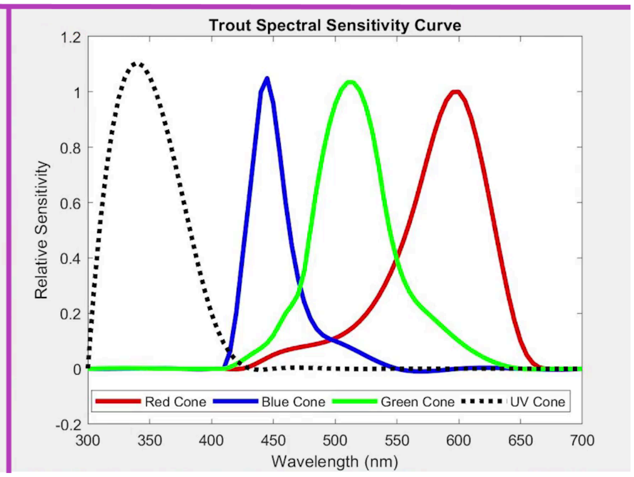
Cones capture light at narrower wavelengths, allowing the perception of color. They give sharper vision than rods, but require higher levels of light. Mammals will concentrate cones in the center of their vision (the fovea), whereas fish have more cones in the periphery of their eye–the portions of the retina that monitor in front, above, and behind. In the case of trout, the highest concentrations of cones are in the portion of the retina that sees in front and above. Trout however are not able to pack in as many cones as the human fovea, and are calculated to have a visual acuity of only a fourteenth of ours.

Humans are born with cones that receive light in three separate wavelengths: blue, green and red. Trout are born with four: ultraviolet, blue, green, and red.

Human Cone Spectrum



Trout Cone Spectrum



I first heard about trout sensing UV light more than a decade ago, and noticed it spawned a whole bunch of new fly-tying materials. More recent research has shown very young trout (parr) that have UV receptors have a demonstrated advantage in feeding on diatoms (zooplankton). However, when they grow to just a few inches long (smolt) and start feeding on insects, their UV receptors convert into blue light-sensing cones. Putting an additional nail in the UV coffin, even more recently it was discovered that the lens of an adult trout has an UV filter which keeps UV light scatter from interfering with vision.

Fish and birds share one additional light-sensing structure that mammals don't have–the double cone or twin cone. Scientists have not yet figured out what double cones do, but the most interesting hypothesis I have read is that they are involved in detecting motion.

Light/dark adaptation

Fish don't have an iris or eyelids, and have evolved a different method of both seeing well at night and protecting their retina from light during the day.--their retina will change its distribution of protective pigment and will swap the cones and rods from day to night. Very curious of the exact mechanism of how this occurs, I ended up finding my best explanation in some very old publications [(M.A. Ali, 1975)](). It turns out that cones and rods are anchored side by side in the retina, but they are capable of changing shape by elongating to put their light-sensing apparatus farther from the incoming light, or contracting to put it closer. In addition the distribution of pigment in a protective layer called the Retinal Epithelial Pigment (REP) will vary from day to night. Here is an illustration I found and for which I have clarified the labeling. In this illustration the light is coming from below:

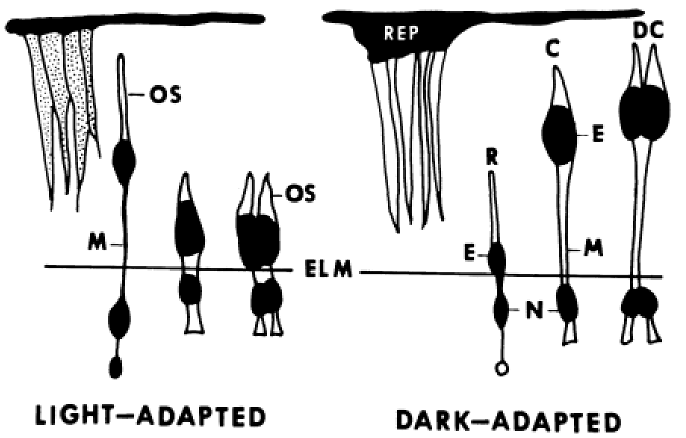


FIG. 1. Diagrammatic presentation of the position of REP, cones and rods in the light- and dark-adapted retinas of a salmonid (modified after Ali, 1958).

REP=Retinal Epithelial Pigment
OS=Outer Segment
M=Mitochondria
ELM=External Limiting Membrane
N=Nucleus
R=Rod
C=Cone
DC=Double Cone

The pigment in the REP (which has the appearance of stalactites in this illustration) keeps the light from bouncing around further once it has passed through the layer of cones or rods. In the light-adapted picture the pigment is distributed throughout the “stalactites”. In the dark-adapted picture the pigment has withdrawn. Notice that during the “day” the Outer Segments (which contain the light-sensing apparatus) of the rods are buried in the REP and the OS of the cones are exposed to light. At “night” their positions have reversed. This adaptation typically takes from 20 minutes to an hour, depending on water temperature and light levels.

Here is a photograph from the same publication showing actual frozen sections of light and dark-adapted retina. I have swapped the sides from the original and relabeled it to avoid confusion.

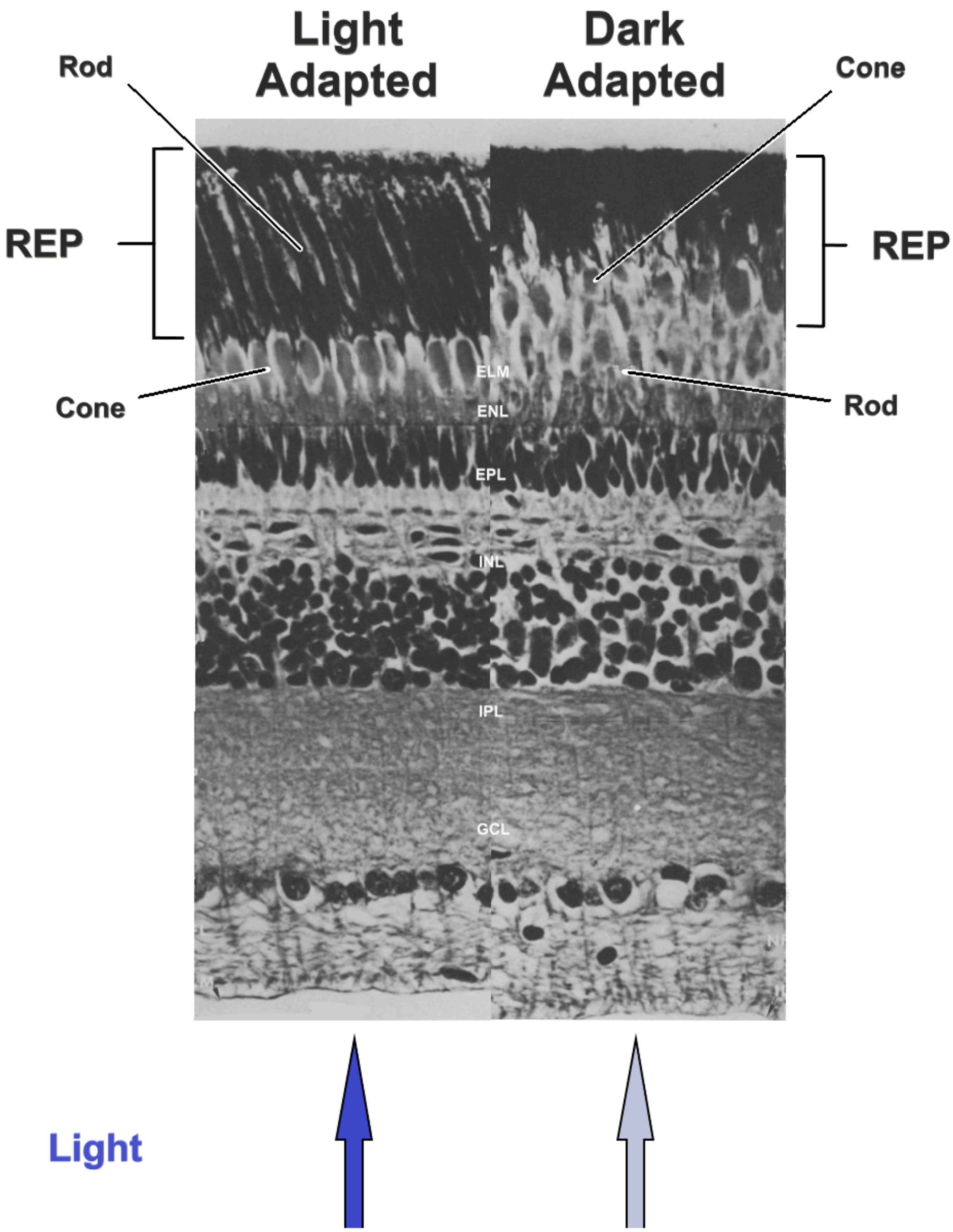


FIG. 2. Photomicrographs of transverse sections of the retina from the ventral regions of the dark- and light-adapted eyes of the Artic char, *Salvelinus alpinus*. The scale indicates 50 µm. REP, retinal epithelial pigment R, rod; C, cone; ELM, external limiting membrane; ENL, external nuclear layer; EPL, external plexiform layer; INL, internal nuclear layer; IPL, internal plexiform layer; GCL, ganglion cell layer; NFL, nerve fibre layer; ILM, internal limiting membrane.

Getting back to practical

Keeping the above information in mind, many fly fishing truisms make a lot of sense.

Daylight fishing:

- Fish low light–fishing is more likely to be successful on overcast and rainy days, as well as early morning and late afternoon
- On bright days, look for fish in deep pools and in shade
- On bright days use light flies, on dark days use dark flies
- Target trout facing away from the sun
- When handling fish on bright days to try to shade their eyes from direct sunlight.

Dusk/Night fishing:

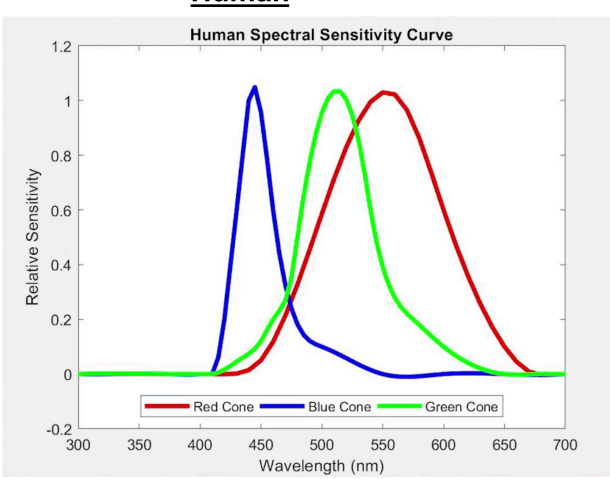
- Use larger flies, especially those that create turbulence
- Use white or silver flies for visibility, or black for a silhouette

So, what about red?

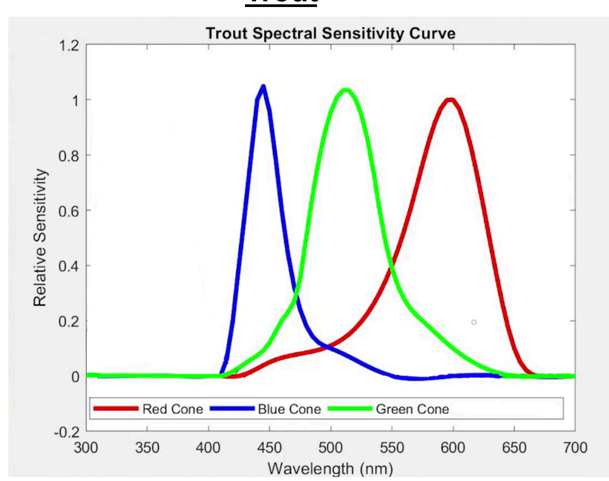
As discussed in my [Stained Water article] the color red will appear dark (even black) in both stained water and in deep water. So, when can red be effective? Red is seen best on bright sunny days, on or near the surface, at short distances, and if the water clarity is good.

There is another aspect about trout and the color red that I learned in doing this research. Going back to the graph I showed earlier comparing retinal cones in humans vs mature trout:

<u>Human</u>

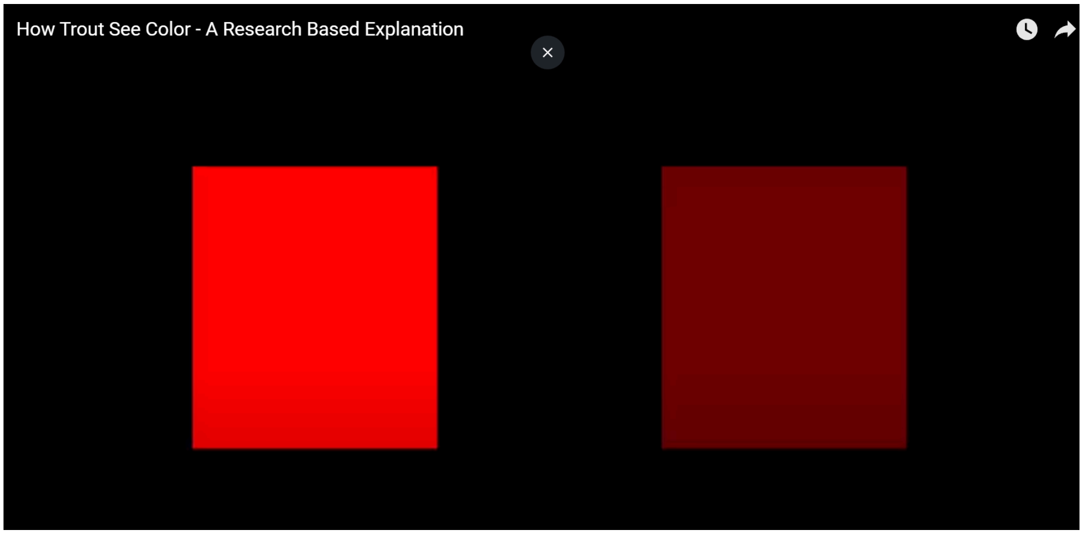


<u>Trout</u>



Notice how the curves for the green and blue cones are nearly identical for humans vs trout, but the red is different? In humans, light of the wavelengths from 450 to 650 nm will stimulate the red cones, whereas in trout only light of 525 to 650 nm will stimulate the red cones. An interesting speculation is that trout will see muted red as bright red.

In this slide the muddy red on the right is what a human would see, but the slide on the left is how we think a trout would perceive the same color:



While this would explain why flies tied with a muddy red remain effective, the most important takeaway for me is not to make the mistake of wearing even muted reds while fishing (since writing this article I have stopped using my favorite cardinal windbreaker).

After researching and then writing these three articles about trout vision, I feel I have a much better understanding on how to select flies (especially fly color) in various situations. I hope I was able to pass along this knowledge to the rest of you.