HOW TROUT SEE

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HAVE YOU EVER WONDERED why a trout will sometimes approach within inches of your artificial fly, pause, then carefully inspect your offering before deciding to strike or refuse it and leave? Certainly we can tell the difference between a standard dry fly and a real fly, even at quite a distance. Why then would a trout waste valuable energy to leave a holding position and scrutinize an artificial fly so closely if its vision were comparable to our own? You might also be inclined to wonder how it is that a fragile insect such as a mayfly can be so easily imitated with bits of fur and feathers tied on a hook. The answers to these questions lie in understanding the visual perceptions of the trout.

Many of the trout's behaviors are adaptations to its visual perception of the world. It is well reported that trout must rely on visual cues for their survival, especially in food gathering, danger avoidance, and reproduction. Until relatively recently, fishermen could only speculate on what a trout is actually able to see. Fortunately, scientific investigation has provided a much more insightful and accurate analysis of the trout's visual abilities. These abilities are very different from our own.

Most fly fishermen may find this discussion of trout behavior startling; much of the rationale presented for the behavior will be contradictory to many well-accepted notions. Unfortunately, these widely accepted notions are the result of misconceptions presented by other authors on the subject of trout vision. Knowing and using the facts presented in this article on vision in trout should lead to a better understanding of fundamental methods in developing and tying effective and realistic fly patterns and in developing effective fishing techniques.

The Trout Eye

TO UNDERSTAND THE TROUT'S VISUAL SYSTEM, it helps to compare the anatomical makeup of their system to our own. Outwardly the trout eye resembles the human eye in many respects; it has a cornea and lens to direct light, a retina to perceive light, and an optic nerve to transfer visual information to the brain (Diagrams 1 and 2). Beyond these similarities are adaptive differences that allow the trout to see in an environment very different from our own.

With poor visual acuity, they must get close to make the decision—eat or don't eat.

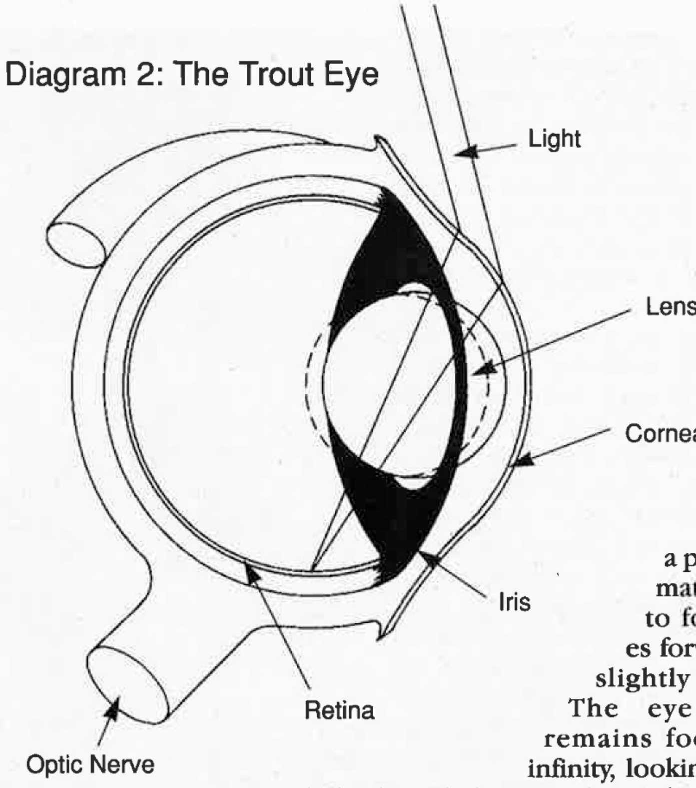
Lacking protective eyelids and positioned laterally along the side of the head, the trout's eyes are located to provide an extensive peripheral field of vision. The cornea of the eye actually protrudes slightly from the side of the fish's head and renders it vulnerable to injury. The trout is able to move its eyes in a coordinated fashion by use of several muscles attached to the outside portion of each eye. By experimentally moving the eye with tweezers, scientists have demonstrated that the trout has a range of ocular motion comparable to that of the human eye.

The Visual System

A DISCUSSION ABOUT VISION in any visual system is incomplete without a fundamental understanding of how light moves through space and how visual images are formed. Light travels through a vacuum at a constant speed. When light enters a medium with a different optical density, the speed of the light changes, and at the interface between the two materials the light bends. This bending of light is called refraction. Understanding refraction is an essential part of understanding how visual systems bend light in order to focus light on the retina to form a clear visual image.

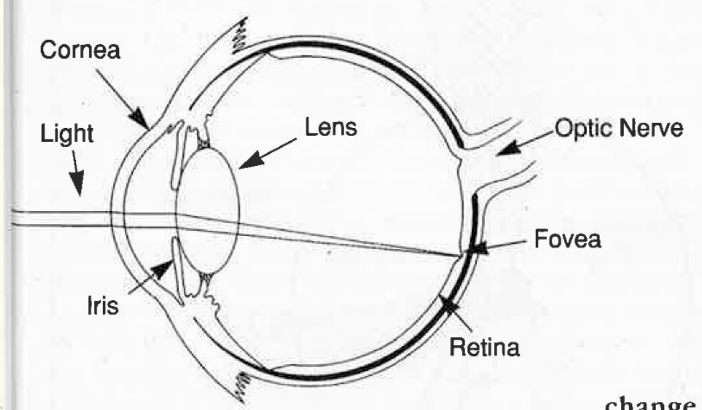
Because of the large disparity in optical density between air and cornea, the human eye bends incoming light primarily at the air/cornea interface through the process mentioned above, refraction. The relatively weak lens of the human eye fine-tunes the focus of incoming light onto the retina to provide us a clear image. In trout eyes the opposite is true, as light is bent very little from water through the cornea, because both of these substances have similar optical densities, hence refraction of light is minimal. A powerful lens is then necessary to focus incoming light onto the retina of the trout. The lens of the trout's eye is so powerful that it is roughly spherical and actually protrudes through the pupil. Despite the high power of this lens, it is remarkably free of visual distortions, another miracle of evolution.

Diagram 2: The Trout Eye



In order for the human eye to focus on both near and far objects, the lens must change shape to increase or decrease its power. While at rest, our eyes are focused at infinity, allowing us to see distant objects effortlessly. To read something up close, our lens power increases until the material focuses correctly. As we reach the age of forty-five and older, our lens loses much of its ability to change shape, hence the need for bifocals or reading glasses for close work.

Diagram 1: The Human Eye



ROD WALINCHUS ILLUSTRATIONS

In contrast, the lens of the trout does not change shape to focus as it does in the human. Rather, the entire lens moves in a plane forward and backward to focus an image in the back of the eye (Diagram 2). While at rest, the trout's eye is focused at approximately three to four inches forward and slightly upward. The eye always remains focused at infinity, looking laterally, backward, down, and straight up. When the trout's lens is retracted in a focusing effort, the fish is able to see forward to infinity while the focus of other positions of gaze remains essentially unchanged. In this way the trout may actively focus its eyes only looking forward, while the remainder of its visual field is focused in the distance. Because the lens of the trout eye is very powerful, objects from approximately six feet and beyond are all in focus on the retina at the same time when the fish gazes at distant objects.

It may seem confusing how so much information about the peripheral environment could possibly be perceived at the same time by the trout. As with humans, the trout probably has an area of conscious awareness in its most developed field of gaze looking forward. The peripheral fields of gaze are probably subconsciously perceived until movement or contrast is detected and draws the conscious attention of the fish. Carrying this analogy to the human visual system, we commonly perform tasks with our central vision without being continuously aware of the details in all of our 180 degrees of peripheral vision. Typically we do not notice objects in our peripheral fields until changes occur in color or movement to draw our attention to these areas.

Contrast in color and hue between objects helps us discriminate them more clearly, particularly at low levels of light or at the limits of resolution. This becomes particularly important for the trout. Although the trout cannot sharply see an overhead predator or the silhouette of a fisherman in its peripheral vision, the movement of these objects against a contrasting background draws its attention and the trout flees for cover. Many fishermen through trial and error—mostly error—are well aware of this fact and have learned to reduce contrast between themselves and their environment through the use of camouflage clothing or fishing in shaded areas. Avoiding sudden movements also reduces the chances of detection by the trout. An emphasis should be placed on slow, careful wading and controlled casting motions.

Although trout have an extensive field of peripheral vision, it is worth mentioning their four areas of blind spots. Due to the anatomical positioning of the trout's eyes, it is unable to see directly below, directly behind, just in front of its snout, and just above its head (Diagrams 3 and 4). Fishermen who cast directly upstream to a fish attempt to take advantage of the trout's rear blind spot and in this way remain undetected by the fish. In reality, a trout that moves the least bit from side to side shifts is peripheral vision enough to detect a threat at its rear. In this way the trout will most likely see the fisherman if he draws attention to himself.

While the trout's eyes are well positioned to view the surface of the water from a relatively horizontal position, it is unable to focus below to the bottom of a stream from this position. In searching for food items near the bottom, the trout must position itself with its tail elevated and head pointed downward. Only in this position can it focus to see the bottom with both eyes.

The ability to adjust the amount of incoming light into the eyes is important for optimum viewing and preventing overexposure of the retina to sunlight. Our eyes may adjust the amount of incoming light by constricting or relaxing the iris, which in turn changes the size of the pupil. Because the trout's lens extends through the center of the pupil, it is unable to adjust the pupil diameter as humans do. Rather, the trout's retina has an associated, specialized layer of pigment granules that actually moves in response to light and is able to protect one variety of very sensitive retinal cells from overexposure to sunlight. This process is aided by the additional movement of the photoreceptive cells. Unlike the pupil response in humans, which occurs in a fraction of a second, the migration of pigment granules in the trout's retina requires several minutes to occur once it is stimulated by bright light.

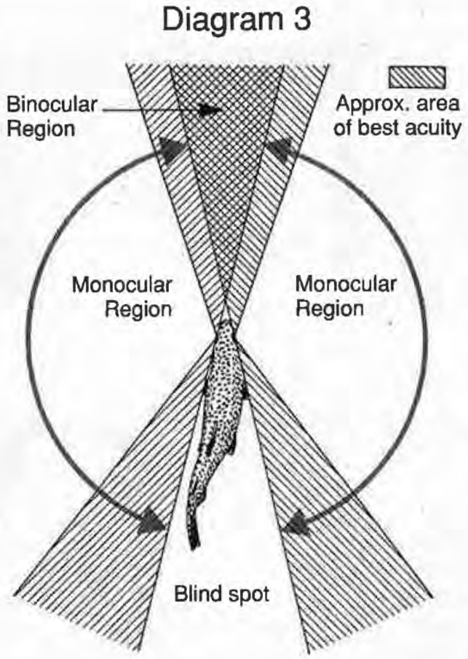
The retina is a specialized tissue that lines the back of the internal eye. It is capable of sensing a wide spectrum of light wavelengths and intensities through a photochemical reaction that in turn produces signals that are transmitted via the optic nerve to the visual centers of the brain. The brain reconstructs the signals to perceive an image.

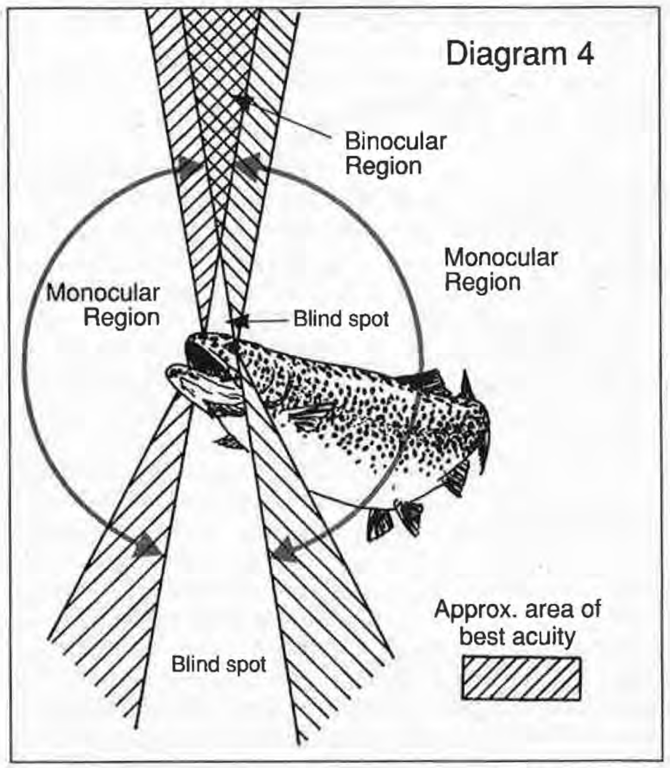
The photoreceptive units of the retina may be divided into cell types known as cones and rods. Cones perceive colors in normal daylight viewing. The rods, which are unable to discern color, are approximately one thousand times more sensitive to light than cones and allow vision at very low levels of light (starlight). The human eye possesses three types of cones that allow us to see in the blue through red color visual spectrum.

Young trout possess four types of cones with color vision extending from the ultraviolet range through red. As the trout gets older, the cones responsible for ultraviolet perception regress, and the retina reverts to a three-cone system similar to that of the human. The cones responsible for vision into the ultraviolet range may allow young trout to better feed on small aquatic life. If true, this represents yet another adaptation of the trout's visual system designed to enhance survival.

The rods found in the retinas of both humans and fish are only useful for vision at low levels of light. In order to see with our rods, the retina must adapt from a daylight system to a night-vision system, a process that usually takes from 20 to 30 minutes. This period of adaptation of the retina explains why fish stop feeding for about half an hour just after dusk as their eyes adjust from seeing with cones to seeing with their very light-sensitive rods.

Interestingly, the trout's eyes are not the only organ of its body to possess vision receptors. The brain of the trout contains a small center called the pineal gland, located just beneath a portion of the relatively translucent skull, and it responds to input of light and dark signals from overhead. The pineal gland is thought to function as a calendar for the fish which helps regulate body cycles based on daily and seasonal variations.





ROD WALINCHUS ILLUSTRATIONS

Diagram 3 shows the horizontal visual field of the trout. Diagram 4 shows the vertical visual field. The trout has monocular vision to its sides. The single-hatched area shows the area of best acuity. The double-hatched area shows the area of binocular vision, where both eyes see with good acuity. Blind spots occur behind, below, above, and in front of the fish.

The trout's brain contains a small pineal gland that responds to input of light and dark signals from overhead. The gland is thought to help the fish regulate daily and seasonal body cycles based on changes in the light perceived.

MICHEL ROGGO PHOTO

How and what we see of our environment is directly related to the arrangement of rods and cones of the retina. The human retina possesses a central, small area that is highly specialized, known as the fovea (Diagram 1). This region consists solely of numerous tightly packed cones and provides us our best daylight visual acuity. The adjacent retina consists of a diffuse mixture of cones and rods with rods predominating. Because of this array, humans possess excellent central daylight acuity for approximately five degrees, but our acuity drops off dramatically in our peripheral vision. The correlation to this arrangement is that at very low levels of light, starlight for example, we are unable to look directly at something and see it accurately. This is because our cones lack sufficient sensitivity at these low levels of light. By looking slightly to the side of what we want to see, we place a focused image in a region of retina concentrated with rods, and the image is perceived, although no color is detected.

The trout retina is organized much differently from our own. Having no central fovea, it rather has a ring-shaped area of peripheral retina that is concentrated in cones. Because the concentration of cones in this region is substantially less than that of the fovea in the human eye, the resolving power or acuity of the trout eye is only a fraction of the acuity of a human eye. The location of this specialized ring of retina in the trout affords the best daylight vision peripherally, exactly the opposite of the human. This means that a trout sees best forward, backward, up, and down but has poor acuity laterally because the corresponding central retina has relatively few cones (Diagrams 3 and 4).

It should be noted that the regions of greatest visual acuity overlap forward and above the fish, providing the trout a long but narrow arc where it sees best binocularly, using both eyes together. Given this fact, it is not surprising that trout tend to feed in lanes, often ignoring flies just a few inches laterally, simply because they do not see well in this direction. To cover a larger area for feeding, the trout would have to swim back and forth, scanning the above water surface and wasting a tremendous amount of energy against the current, something no wild fish can afford to do.

Because the trout's peripheral specialized region of retina retains the presence of very light-sensitive rods, it is able to see at night by simply looking directly at its quarry. In this regard the trout's eye is better adapted than a human eye for hunting at night. However, due to the way the rods collect visual information and transmit it to the brain, the fish's nocturnal visual acuity is probably less than its daylight acuity.

What the Trout Actually Sees

THE DAYLIGHT VISUAL ACUITY of the trout has been measured experimentally in a laboratory study by three

MICHEL ROGGO PHOTO

German scientists using a particular behavioral pattern of the trout combined with an experimental apparatus to accurately measure acuity. Their results correlate closely with the calculated visual resolution based on the optical properties of the trout eye and the measured distance between cones. The scientists found that the visual acuity of the trout was 14 times less than that of a human.

The fact that trout only see a fraction as well as humans do explains a characteristic feeding pattern of the fish. Most fishermen have seen trout move from a holding position near the bottom of a stream to approach within inches of a fly to closely observe it before feeding. At a few feet away the trout is only able to see a fuzzy silhouette of the fly, which initiates its interest in the object. As the trout gets closer to the fly, its image projected onto the retina proportionally enlarges until the fish can discriminate it conclusively from other surface objects that might resemble a fly. Once the trout decides if the object is on its menu that day, it either strikes the fly or returns to its holding position.

Through the Trout's Eye

The visual acuity of the trout can be closely approximated by taking a picture and altering the focus a calculated amount. Photo 1A shows what a human might see of a standard dry fly from directly underwater. Photo 1B is what a trout sees of the same fly at a distance of one foot. Photos 1C and 1D are what a trout sees at six inches and three inches from the fly, respectively. Notice that as the fish gets closer to the fly, it is able to resolve more details, although the acuity remains unchanged. At approximately three inches from the fly, the trout reaches maximum visual discrimination.

Photographs 2A and 2B, modified from a photo provided by Dr. Carl Richards, demonstrate what a trout sees of the mayfly ***Baetis hiemalis*** at a distance of six inches and three inches, respectively.

Previous authors and researchers on vision in fish have attempted to refract various species of fish both in and out of the water. Refraction is basically a method to determine if spectacles are needed for the eye to achieve its best vision, a procedure that anyone who wears glasses is familiar with. Initially, trout were thought to be nearsighted. Later, researchers using measurements of light reflected from the fish's eyes felt that the trout was farsighted. Most recently, studies using sophisticated electronic recording devices from the fish's brain have proven that most fish have little refractive error and that the previous methods for testing refraction were inaccurate. The significance of this to the fly fisherman is only to clarify this topic which appears in other material on vision in trout.

Binocular and Stereo Vision

One major consideration now remains concerning vision in trout. Do trout have binocular vision as most humans possess, or are they essentially monocular, using input from one eye at a time? Binocular vision is an ability of the brain to take visual information from two eyes and form a single image. For this system to exist the eyes must be able to both "lock on" to a target and maintain coordinated tracking. Although research has not proven the trout to be binocular, observations of the fish demonstrate a consistent pattern of moving the eyes together in small tracking motions. For this and other reasons most researchers speculate that trout do possess binocular vision.

Binocular vision can only exist in fields of vision shared by the two eyes. As was mentioned previously, this correlates to a common area forward and above the trout (Diagrams 3 and 4). This region of binocular vision is ideally suited to a creature that holds near the bottom of a river and must scan both forward and above for food that washes downstream.

Stereovision, or the ability to see in three dimensions, is a higher-level function of the brain that requires the presence of binocular vision. Most people with binocular vision can see in three dimensions, although some cannot. If we assume that a trout does have binocular vision, it is possible to make speculations about its stereoacuity.

Experimentally blurring the vision of a human to the level of a trout reduces stereoacuity by approximately 100 times to a very rudimentary level. It is essentially impossible for a creature with the visual acuity of a trout to possess high-grade stereoacuity. How then are trout able to feed on moving insects without this ability?

Actually, most of our clues to depth perception have little to do with stereovision. Many people with poor or nonexistent stereoacuity have little difficulty driving cars or performing manual tasks. They are accustomed to using clues of size, shape, and shadows to help judge distance and direction. The fact that trout not infrequently miss the fly during a strike points to a certain lack of stereoacuity. Certainly the fish is successful most of the time. Proving that stereoacuity is not necessary for trout to feed or survive are the numbers of hook-injured monocular fish that survive and feed

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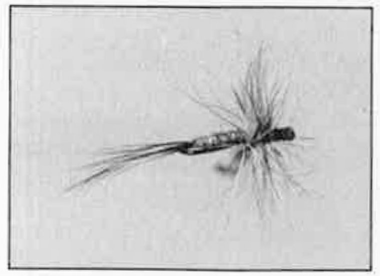

Photo 1A. Depicts how the human eye sees a standard dry fly from underwater.

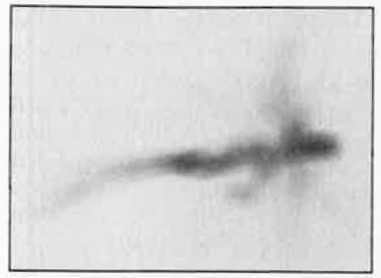

Photo 1B. How the trout sees the same dry fly at a distance of one foot. The fly's details are lost.

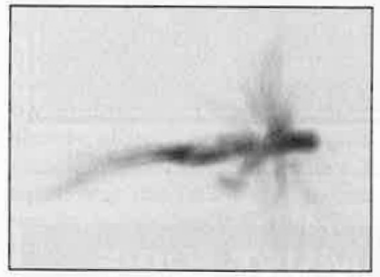

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Photo 1C. How the trout sees the same fly at a distance of six inches.

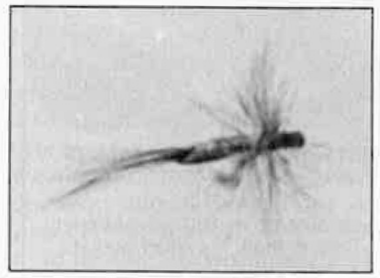

Photo 1D. The trout reaches maximum visual discrimination at three inches from the fly. The fly's details become visible.

How Trout See . . .

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despite their visual handicap.

In summary, trout possess a visual system which is adapted for underwater viewing and is quite unlike our own. Although we surpass the trout in visual acuity, the trout has a much larger area of visual surveillance and is better adapted to hunting at night. Much of the trout's behavior is governed by its visual abilities and limitations. This

Photo 2A (above) depicts how a trout sees a mayfly at a distance of six inches. Photo 2B (below) shows how a trout sees the same mayfly at a distance of three inches.

DR. CARL RICHARDS PHOTOS

is most apparent in observations of the trout's close scrutiny of flies and use of feeding lanes. Comprehending the visual capabilities of the trout provides a better understanding of why this creature has gained the reputation as a wary, yet selective, predator.

Fly Design

FUNDAMENTAL TO THE DESIGN of artificial flies and fishing technique is a clear understanding of how and what a trout sees. Using information presented here as a foundation, I am currently investigating questions that I have found puzzling for years. Specifically, how can artificial flies be modified to make them appear more realistic to a selective trout? How small must a tippet be before it becomes invisible to the trout? Can the hook be modified to make it less conspicuous? Which methods of fishing are least likely to disturb a wary fish? Perhaps these and other questions can be answered by further visual investigation.

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