Light and colour for fly fishing and tying

Craig Thom

***"A trout's ability to see and recognise colours as we see them is one thing, but to know what [the trout] can see is another and more important matter,"* Lee Wulff.**

There is a lot written about what trout can see, but most is biased towards seeing from a human perspective, and the tendency of writers to anthropomorphise (try and say that fast!) is hard to resist. However, we need to understand that fish do not think like us, and although their visual system is similar to ours, what the fish sees and perceives is vastly different.

What every individual animal sees is subjective, and because of this, our visual systems do not show exactly what is in front of us. We *perceive* colour and objects *subjectively*, which is influenced by not only physiological, but also psychological factors. There is no colour until the light 'waves' have hit our retina, are converted to pulses and then interpreted by our brain. *If a green tree falls in a forest and there is no-one to hear it fall, does it make a sound? Was it a green tree, if there was no eye to see it?*

> **Subjective** - Proceeding from or taking place in [the] mind rather than the external world.
> *(thefreedictionary.com)*

The crux lies in the word **perceive** because what we or the fish 'see' is subject to subjective interpretation by two vastly different brains. This is put very succinctly by Parker[2]. "*For the brain to identify an object, the object must possess all the characters associated with its definition in the brain's dictionary, like a set of numbers to open a combination lock.*"

This *perception* allows us to catch fish with flies that have hooks sticking out them and leaders attached. This is because these objects have no place in the fish's frame of reference and are simply ignored.

"*Whoa!*" you cry, "*but what about selective trout and those who have learnt a few tricks of the trade?*" This is a popular statement in trout literature, but give it short shrift, and remind yourself how intelligent these fish *are not.*

Obviously a line smacked down over the water is going to spook a fish, even though it does not know what the line is. In this case it is the suddenness, noise or shadow, not the line itself. Strange objects drift over and past fish all the time, especially areas closer to 'civilisation'.

The phrase 'selective trout' should be banned! 'Preoccupied' is a far better word and makes more sense. Fish aren't choosy, but they can get preoccupied with a particular food source for a period of time.

The trout is a visual predator with half of its brain dedicated to the eye, leaving little space in an already small brain for other activities. Our own brain is also quite visual (and very big), but we can still be tricked. Here's an example of how you can see something that isn't there. You can also miss things that are there. So how easy is it to fool a smaller, more primitive brain?

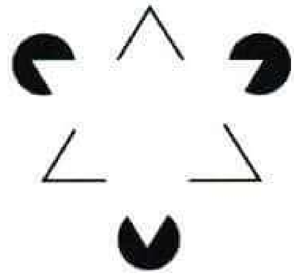


Figure 1 Kanisza's triangle. A white triangle appears that doesn't actually exist in the diagram.
"the visual system sets the rules for the characteristics of [an image]," Parker[2]

Looking at the trout brain again, half is used by the eye (or visual processing), and the balance is left for the other senses (especially the lateral line). After that, space is used for reflexes and the pituitary gland, leaving precious little for 'thinking' or contemplation. And I haven't even covered priorities like reproduction, food and survival. Because there is little space for 'thinking', its primitive brain needs to 'concentrate' on a *priority event*, which is a something an angler can exploit. Provided you have not spooked a fish you can tempt it with a fly. Once the food is seen, the brain will be dedicated to nothing else (you have 'lock on').

That small brain is doing a simple logical exercise; *"Am I in danger? - No"*; *"Is it out of context? - No"*; *"Does it look like food? - Yes"*; *"Eat it? - Yes"*.

It is your job to ensure that a fly 'behaves' like food and 'looks' like food. Making it look like food entails a bit of work. Some of the main criteria of fly design we need to work with are;

KISS ME. **K**olour, **I**mpression, **S**ize, **S**hape, **M**ovement (behaviour) and **E**nvironmental Context. Keep this in mind and you should have no problems.

This article will concentrate on Light, and its handmaidens, the Eye (vision) and Colour. Opinions will be kept to the minimum, with facts and scientific studies being the norm.

Part 1 - LIGHT

The House of the Rising Sun
When examining light and water, we first need to look at the source of the light, the sun. Light hitting the water, not only comes directly from the sun, but from the sky as well. Skylight makes up a significant portion of the light hitting water because sunlight is scattered by the atmosphere, but still reaches us via the sky (blue is scattered most, hence a blue sky). Skylight is even more significant in cloudy or overcast conditions. Not all light is born equal; skylight (white) light is made up of several different colours (think rainbow). Each colour is represented by a wavelength, usually shown in nanometres (nm). It is important to note that colour and wavelength are not the same. Wavelength is an absolute and colour is subjective.

The quantity and energy value of each wavelength (colour) reaching the earth differ, and to make things more complicated, our eyes (and fish eyes) are not equally sensitive to each colour. This is represented by a sensitivity curve, shown in Figure 17. You will see that the colour sensitivity curves of trout and humans are quite different.

At noon (Figure 2) sky light has a huge blue component, with less on the red side. At sunset (Figure 3) and sunrise, it's the opposite, but with a lot less light available. The sky colour looks a little lighter, but the clouds (and sometimes the sky) go red. Blue has been absorbed, letting more red through. What does this have to do with fishing? Well, ambient light colour affects the intensity of fly colour, and that is important to know. Also, light available to fish diminishes sharply once sun reaches 10° from the horison.

Light hitting water is subject to many factors, like *refraction, reflection* and *polarisation*, all of which are important to anglers, and will be discussed shortly. Of utmost importance to note, is that once light enters the water, some colours are absorbed more than others.

The amount of daylight on the water on a sunny day is over 100 000 lux and, by comparison, a shaded area will have only 20% of this light, and on an overcast day 10 - 25%.

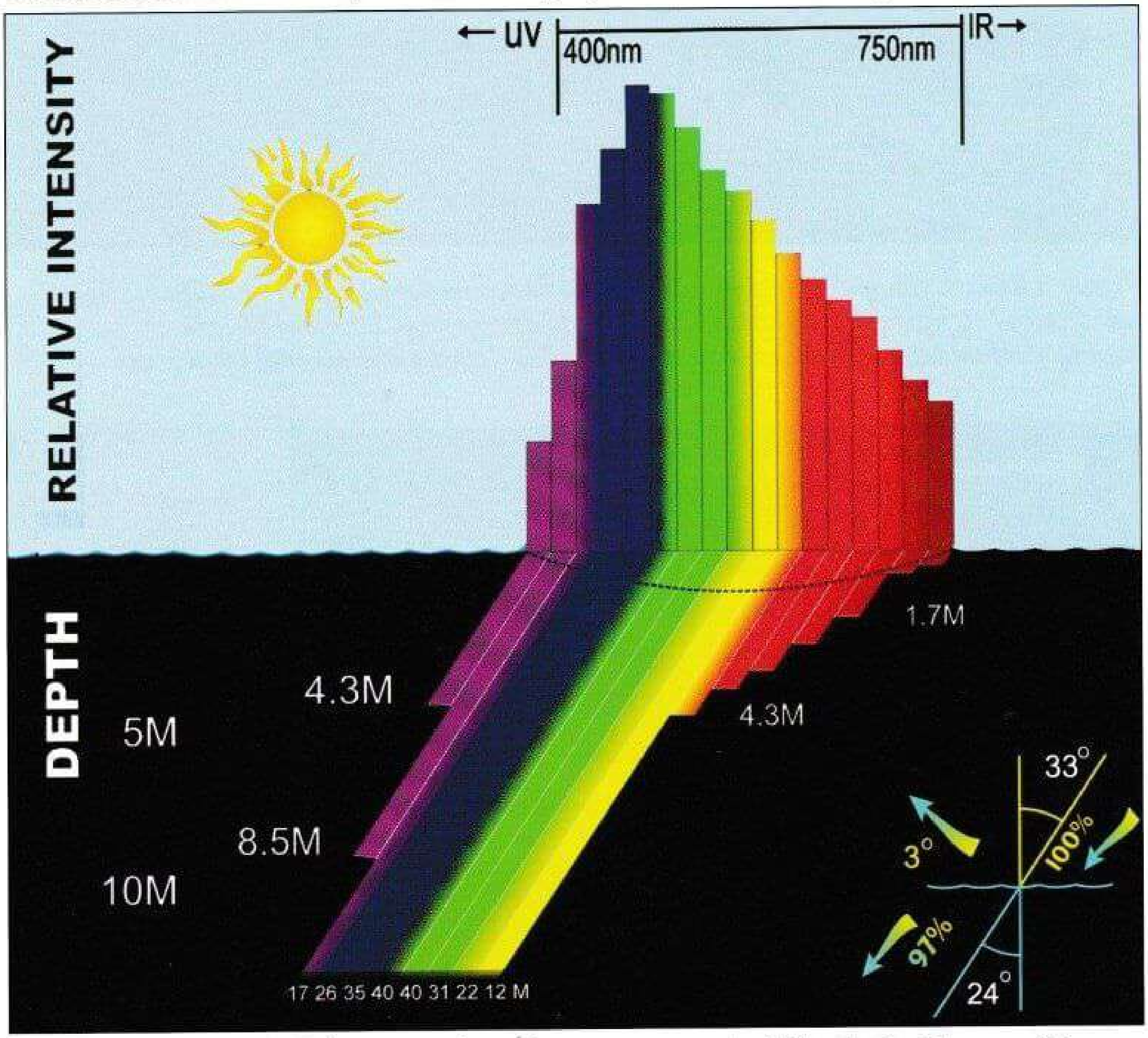


Figure 2 Available skylight across the colour spectrum at midday in the Cape, and how far these colours penetrate pure water (dotted line shows turbid water).

At sunset and sunrise on a clear day the light is as low as 400 lux[13]. Moonlight clocks in at less than 1 lux, and starlight less than 0.001 lux. For trout this is plenty of light. Rader et al.[4] demonstrated that brown trout show a startle response to hand waving at light levels as low as 0.0001 lux, and for rainbow trout only 0.012 lux.

Light hitting the water at approximately 33° refracts into the water at about 24°. The amount of reflected light is minimal (about 3%). As can be seen, red wavelengths are absorbed in the first few metres of water. Blue wavelengths are more readily absorbed if the water contains average or abundant amounts of organic material.

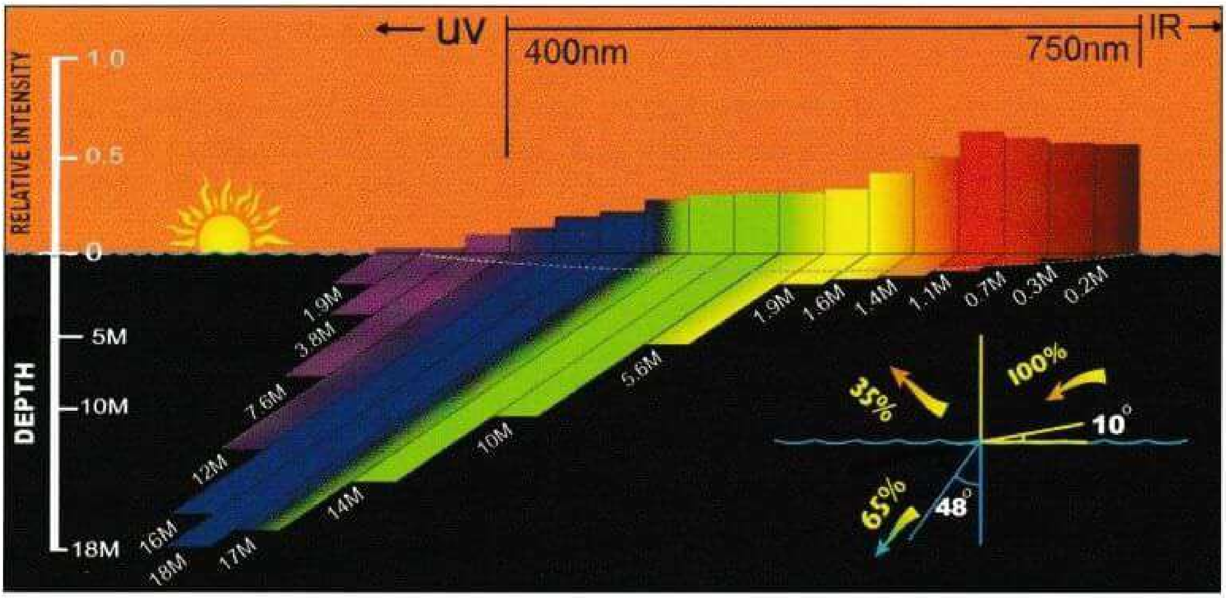
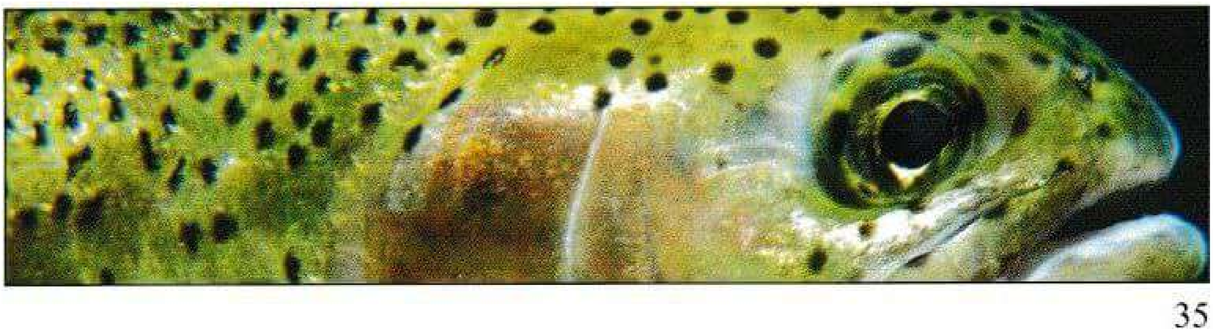


Figure 3 Sunset. Compared to figure 2 you will notice that the amount of available light has dropped significantly. The blues have all but disappeared (absorbed by the atmosphere) and the reds are more prominent. The dotted curve shows turbid water.

Figure 4 Colour chart to determine how to use fluorescent colours for better fly visibility

Figure 5 Colour mixing of pigments, paint and fluorescent pigments

Figure 6. Colour comparisons in the Holsloot River, Western Cape.



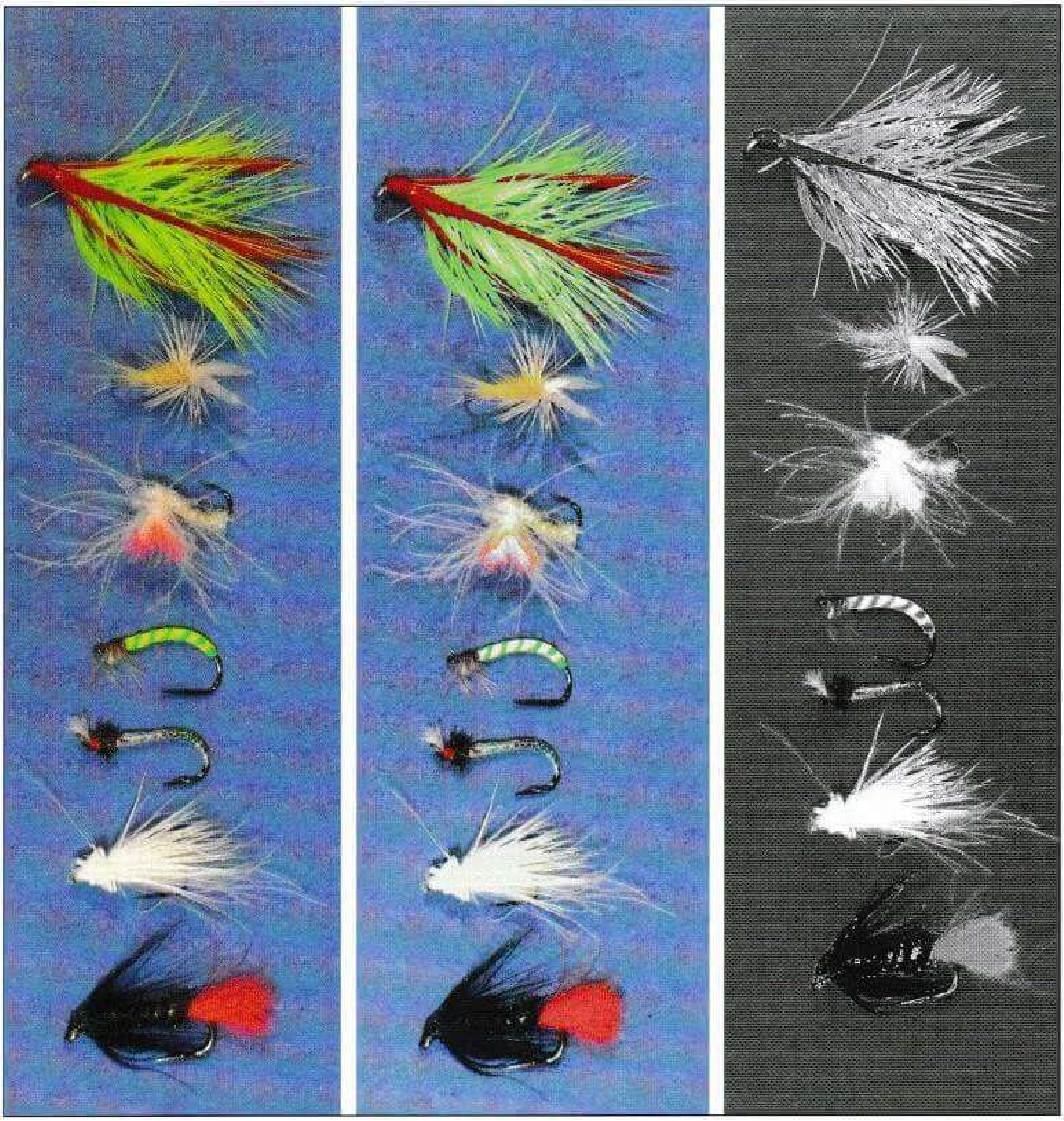
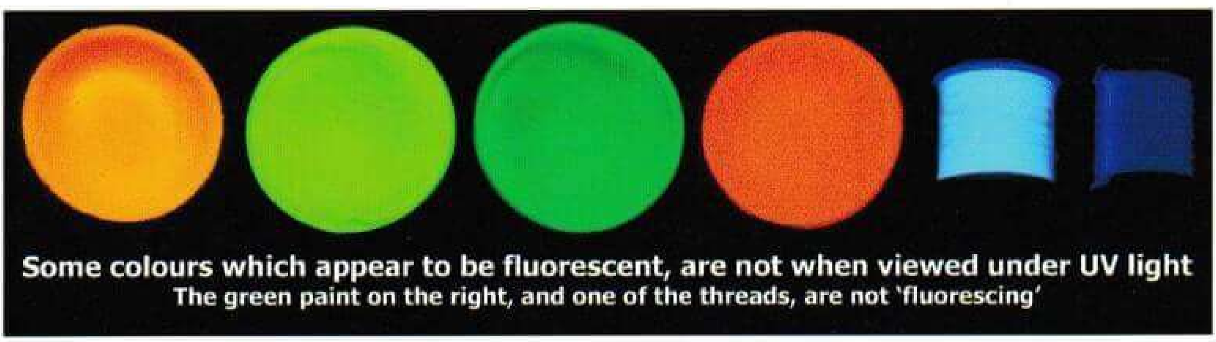


Figure 7 (above). A comparison of some flies, showing normal human vision on the left, and how a fish may see them in clear, shallow water on the right. This illustration has been achieved by layering the UV photo onto the normal, and then reducing the available colours to simulate tetrachromic vision as suggested by Clive Maxfield[7]. How a trout may see flies at night is shown on the right.



Some colours which appear to be fluorescent, are not when viewed under UV light
The green paint on the right, and one of the threads, are not 'fluorescing'

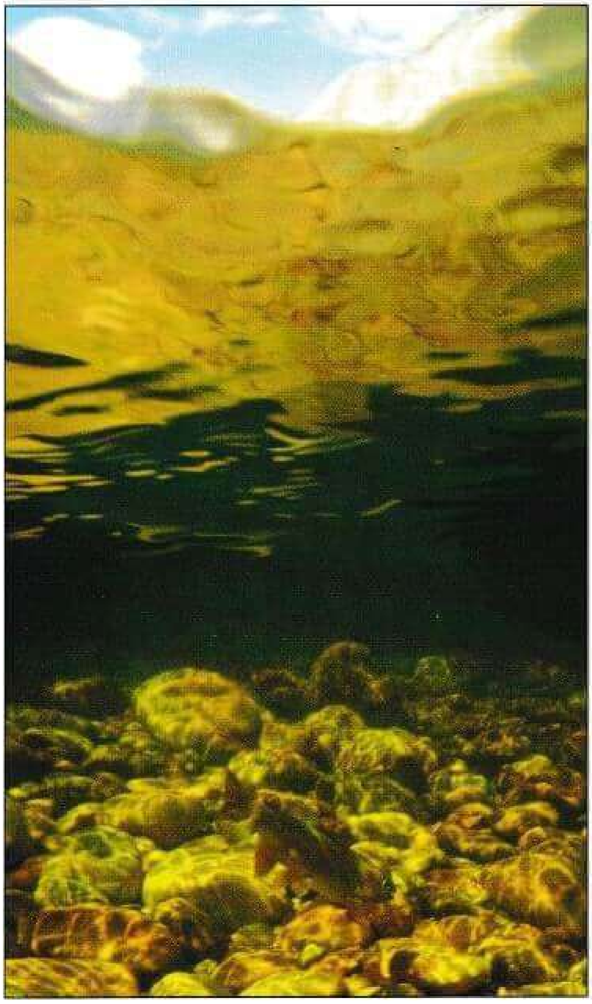


Figure 8 (top) Fish eye view of the water surface. Sky at the top, mountains below it (whitish), with brown a reflection of the bottom against the 'mirror'.

Figure 9 (right) A fly moves towards the mirror / window interface (top to bottom).

Figure 10 (below) Contrast comparisons of colours under different conditions.

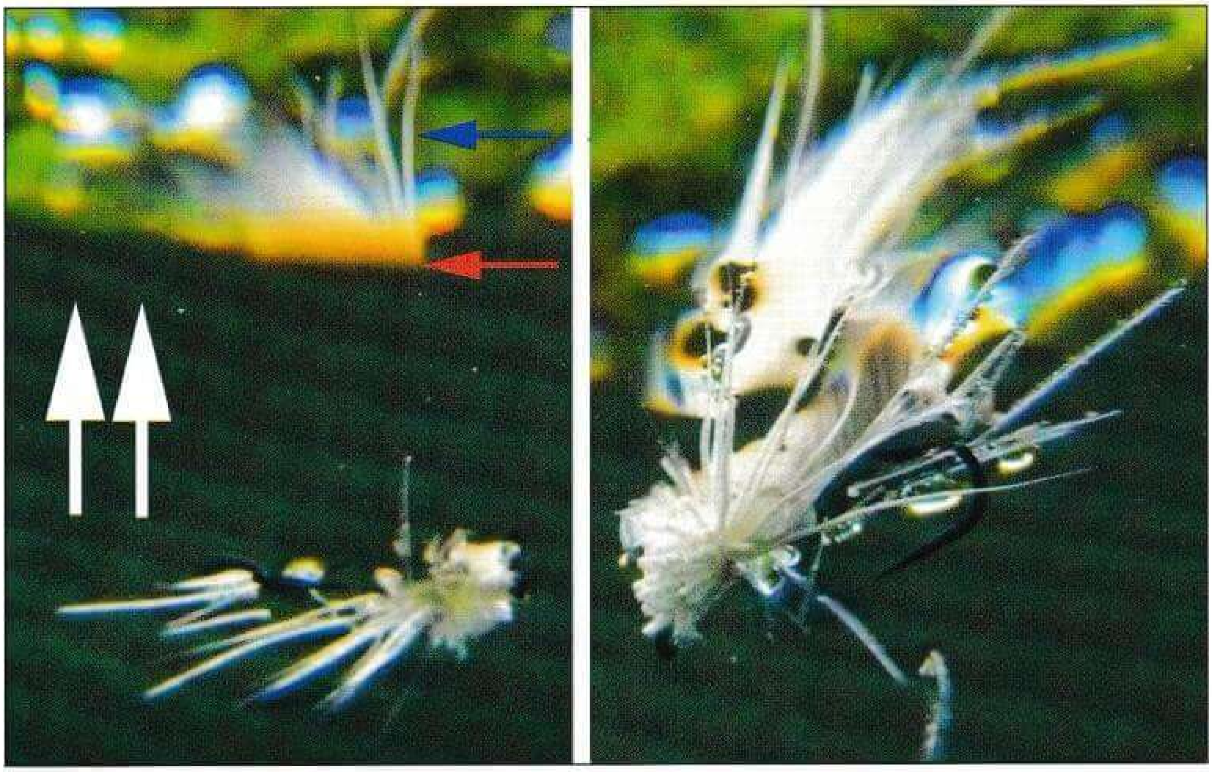


Figure 11 A fly in the mirror (left) moves closer to the window. White arrows indicate direction of movement. Snell's circle, the rainbow effect is shown by red arrow. At this distance from the interface the top portion of the fly is already visible in the window. As it touches the interface (right), more is visible in window. Note the dimples where material pierces the meniscus with their dark patches and rainbows.

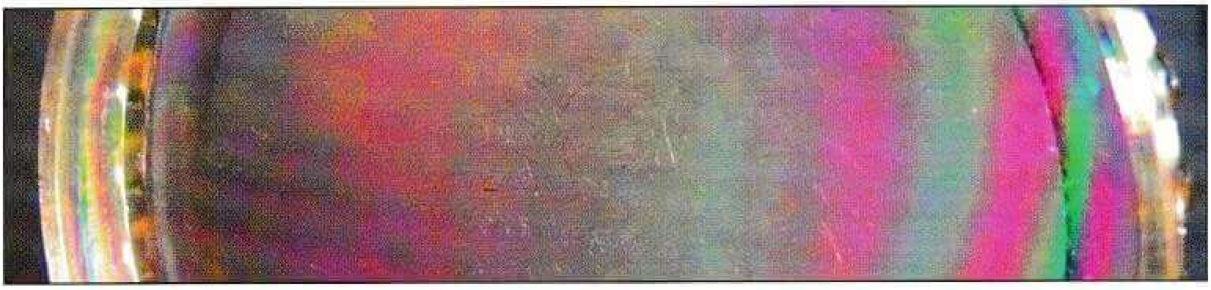


Figure 12 Polarised light through stressed plastic.

Figure 12a Thin film effect on a spent mayfly spinner wings, creating structural colours.

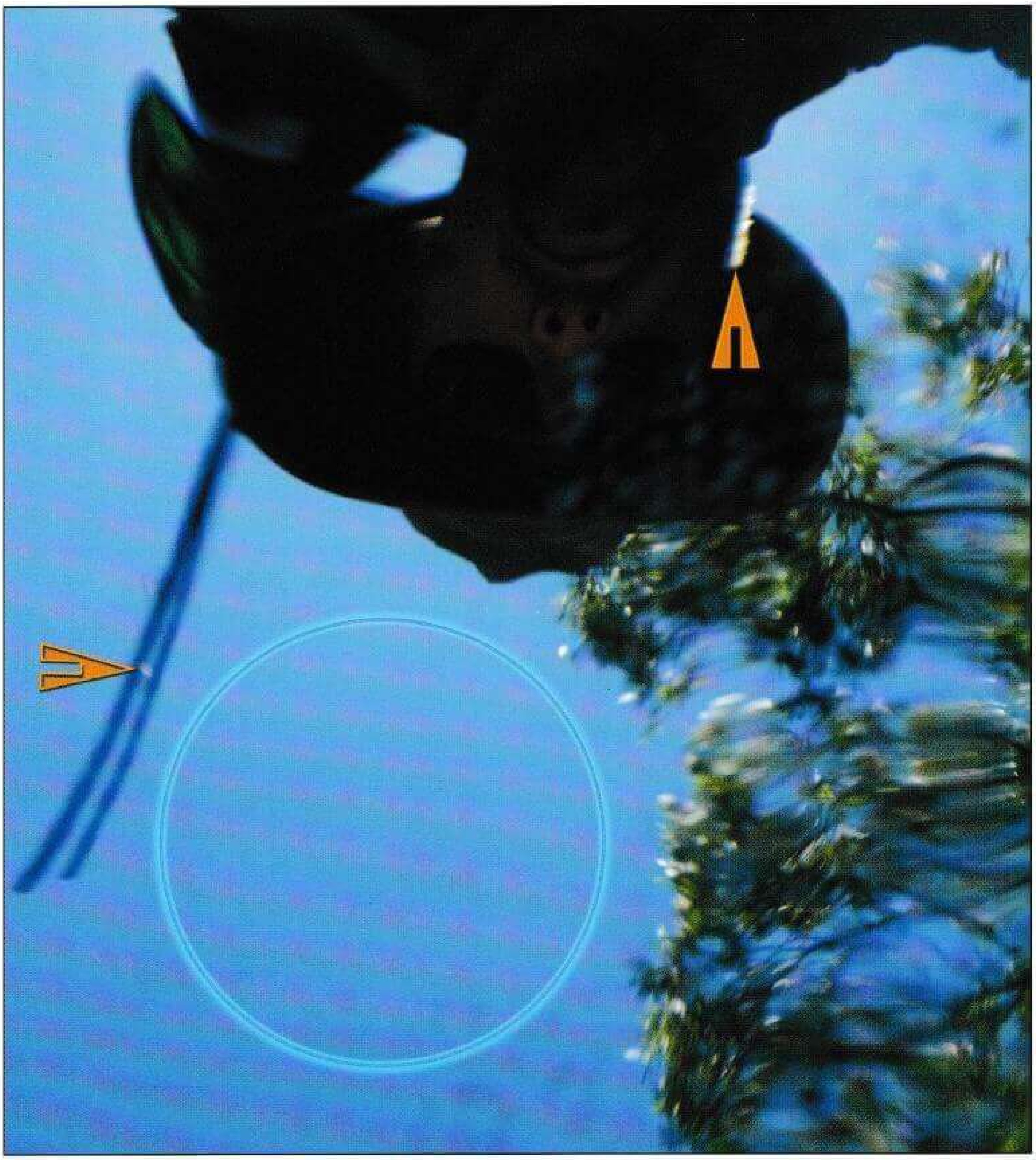


Fig 13 Fish's eye view of an angler. Note how angler and trees seem to loom over the fish. The circle helps demonstrate how things are distorted around the centre of the window. Arrows show sources of flash. The flash at the angler comes from a source not visible in the picture.

Fig 14 Structural colours (above) showing the irridescent colours of a Sunbird (diffraction gratings), Golden Mole (nanotubes) and a peacock feather (photonic crystals).

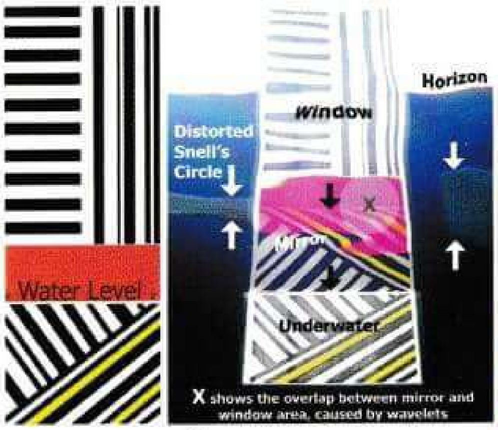
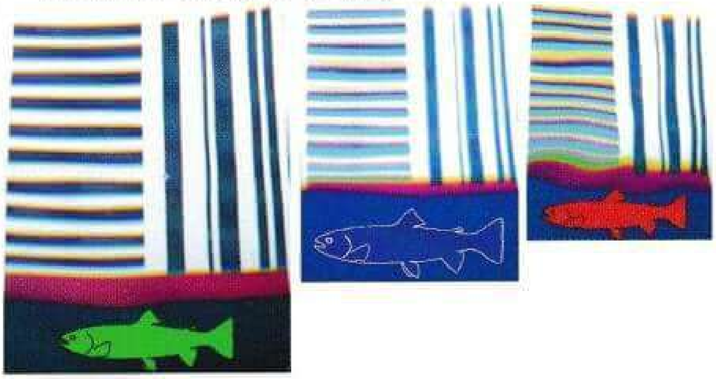
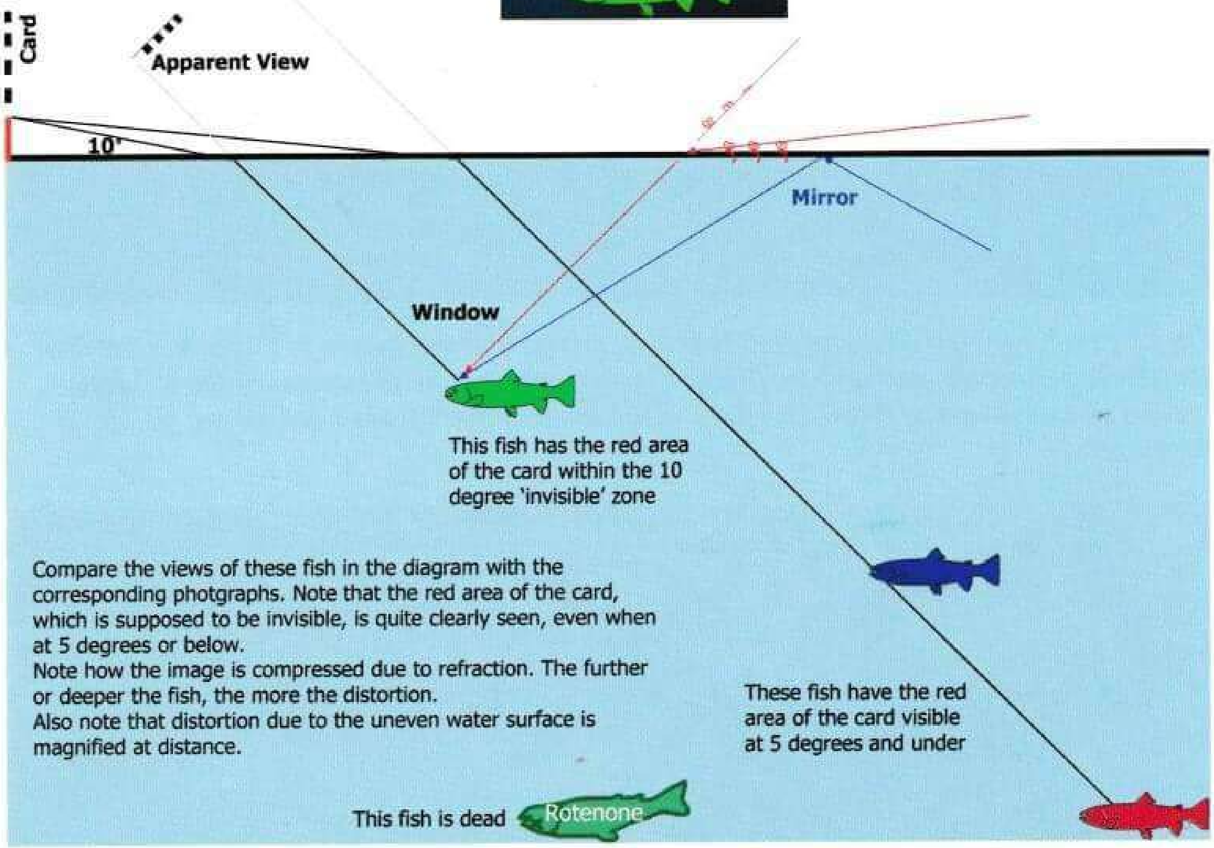


Fig 15 (below) The view fish see from under water, proving that the area below 10 degrees to the water is visible to the fish.





Deep Purple (Ultra Violet)
Unlike humans, trout *are* able see Ultra Violet (UV) light. UV light gives *fluorescent* colours their special glow and this is very significant to anglers. Note that fluorescent colours are not *just* activated by UV light, but any wavelength shorter than themselves. UV light is absorbed rapidly in some water conditions, but studies have shown usable UV at depth. Infra Red light (700nm onwards) has no significance to anglers as it is absorbed by the surface of the water and fish are unable to see it[4].

Fluorescence - The property of emitting light while exposed to light, the wavelength of the emitted light being longer than that of the absorbed light. *(thefreedictionary.com)*

Absorba the Greek (attenuation)
Water eventually absorbs (attenuates) all light, but not all water is the same and not all colours are absorbed equally. The amount of available light in clear water falls by about 10% every 5cm in a logarithmic scale. This is reduced even further by impurities and microscopic fauna and flora in the water. In pure water, red is absorbed first, followed by other colours at different rates (see Figure 2 & 3) Red will be completely absent at about five metres.

In water with a high level of microscopic plant or algal growth, green will be absorbed rapidly. The green is actually scattered (like blue in the sky) giving the water a green appearance. Green water also absorbs colours with shorter wavelengths, so it will have less blue. In water with high tannin content (common in the Cape), brown is scattered making the water look brown or yellow. The yellow appearance of water can also be caused by the breakdown of chlorophyll and humic acids. In this kind of water, greens and blues will be absorbed as they have a shorter wavelength than yellow. Thus if bright colours are required, use reds and oranges, not greens.

Colours are compared in Cape water at different distances (depths) in figure 6. Three comparisons are made at mid morning. The first in clear water at a distance of 2m, the second at 4m in the same water, and the third, 4m but with the sediment in the pool stirred up a bit.

There is little colour loss at 2m, but as we move deeper all the colours start to fade. Note that the fluorescent colours (bottom row right) are already brighter than the normal colours above them.

In the last picture, most colours have disappeared, but blue, green and yellow are still visible. The fluorescent colours which are 'activated' by the blue and green are the most visible. Compare this to what is shown in Figure 2 & 3.

This exercise was also done to demonstrate contrast (figure 10).

In Cape streams, you are catching fish in relatively shallow water, so attenuation effects are not great, except when fishing in tannin stained water. The losses are more significant in still waters, with flies being fished at down to 4m, where most red is gone. At the water surface, distance has same effect on colour as depth, but as a fish gets closer to a fly, the real colours will become visible.

The hole is deeper than the sum of its parts

(reflection & refraction)

Light hitting water will be reflected off the surface and also refracted into the water. Everyone has seen a stick appear to 'bend' in water, and so has seen the effects of refraction. Light 'bends' when it encounters a medium more (or less) dense than the medium in which it is travelling in. How much it 'bends' depends on the difference in densities (or refractive index) of the mediums concerned.

Refraction - The bending of a wave, such as a light or sound wave, as it passes from one medium to another medium of different density.
(thefreedictionary.com)

Refraction is important to us for two reasons. Firstly, a fish in the water is not where you think it is, and the water in which the fish resides is deeper than it looks. The fish is always closer than it looks. This is valid not only when looking at a fish from the bank (like most illustrations) but when you are upstream or downstream from a fish. If you are presenting a dry fly to a fish upstream, and it looks like you have placed the fly right in front of the fish's nose, you have placed it ahead of the fish. Don't forget to compensate!

Reflection - The change in direction of a wave, such as a light or sound wave, away from a boundary the wave encounters. Reflected waves remain in their original medium rather than entering the medium they encounter.
(thefreedictionary.com)

The second important point to the angler concerns the *mirror* and the *window* from the fish's perspective. The percentage of reflection versus refraction depends on what angle the light arrives at the water (Snell's Law). See ***the Magic Mirror*** chapter below as well as figure 15 which gives a good indication of how the view to the outside of the window is distorted.

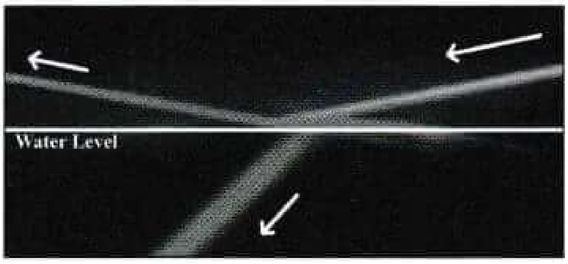


Figure 16 A laser beam shone onto a flat water surface at angle of 10° from the surface.

Light is reflected off the surface, and a significant portion is refracted into the water. Snell's law tells us that at this angle 35% of the light is reflected and 65% refracted into the water. If the water surface is disturbed, the angle at which the light hits the water changes back and forth, increasing and decreasing the amount of light entering the water, but it should average out.

My future's so bright I gotta wear shades (polarisation)

If we consider light as a travelling wave, we have many waves of light striking the water at different orientations. Let's consider two scenarios. One is a light wave travelling in an up and down direction, and the other a light wave in a side to side direction, both arriving at the water surface at an angle. The former (vertical wave) will hit the water and be transmitted into it (absorbed), and the latter (horizontal wave) will be reflected off the surface. The water is acting as a *polariser*. This doesn't happen perfectly, except at Brewster's angle (53° for water). The easiest analogy is a skipping stone. Thrown properly (horizontally) the stone will skip off the water, but if thrown wrong (vertically) it will enter the water. The same applies to vertical and horizontally orientated light.

Anglers experience the horizontal waves as glare, which prevent us from seeing into the water. To counter that, we wear polarised glasses, which are essentially vertical blinds that prevent the horizontally polarised light from getting to our eyes.

The significance of polarisation (other than glare) is that polarised light (PL) entering the water affects how some materials look under water, and that fish are able to detect anomalies in polarisation to detect prey. Figure 12 shows PL shone through stressed plastic creating a rainbow effect. Stretched Clingfilm has the same effect, which may explain its popularity as 'discarded shuck' material in flies. The wings of a spinner on the water surface polarise light, as well as light reflecting off some prey items (See figure 12a).

Polarisation - A condition in which transverse waves vibrate consistently in a single plane, or along a circle or ellipse. Electromagnetic radiation such as light is composed of transverse waves and can be polarised. Certain kinds of light filters, including sunglasses that reduce glare, work by filtering out light that is polarised in one direction. *(thefreedictionary.com)*

It is indisputable that trout (especially juveniles) are able to utilise PL for orientation and migration, but the ability of fish to actually see (not detect) PL is somewhat controversial. Scientists claim to have proven that trout can see polarised light, but others[3] have refuted these studies. So far this ability has only been proven in herring[3]. The distinction between detecting or being sensitive to PL and being able to see PL has to be made.

Being able to detect PL, means that trout can use it to find prey. In turbid water, a change in light orientation could indicate that something edible is likely to be close, and is worth investigating. When a fly or insect distorts the surface film, it distorts the polarisation of the light as well. In calm conditions a fish may be able to detect this change in polarisation before it sees the fly, but a slight riffle on the water may negate this. Sunken flies affect the light, and therefore the polarisation of the light, and are thus 'visible', as PL can make a target object darker or lighter than its background.

Of secondary interest is that Mayflies find their way back to water by the polarised light reflecting off the surface. (They can also end up laying eggs on tar roads for the same reason).

Part 2 - VISION

I have a vision ... a television (trout vision)

As mentioned in the introduction, trout do not see (or interpret) things as we see them. Besides having a different eye and lens structure, the fish has a wide field of view, and can see in all directions at once. And don't go thinking you can sneak up behind a fish in the river because it has a blind spot at the rear. As the fish swims or holds position, so it turns its head from side to side, so it may cover a full 360°. Its blindest spot (as you will see later) is actually to its side. Luckily for the angler it can't see that far, as its view is obscured by moving water, impurities, and obstacles.

In certain areas of view, especially forward, the fish has binocular vision, which is essential for judging distance, especially when chasing prey or engulfing a fly drifting towards it.

Melatonin - A hormone produced in the pineal gland that plays a role in regulating biological rhythms, including sleep and reproductive cycles. *(thefreedictionary.com)*

Me, Myself, Eye

The structure of the fish eye is similar to ours, but with some differences.

1. The fish eye does not have a pupil/iris, and cannot control the amount of light entering its eye. Its eye is also more sensitive to light than ours, letting in about three times more light in daylight. It protects the rods (for night vision) by retracting them during the day. It *may* also use melatonin as a light reduction mechanism in the retina, as the melatonin day/night cycle is opposite to mammals (Besseau et al 2006) [10].

2. The cornea of the fish eye is flat, as little compensation needs to be made between the water / eye interface. Humans need a larger cornea to compensate for the air/eye interface (see refraction).

3. The human lens which has the shape of a flattened sphere, focuses (accommodates) by becoming rounder, which is achieved by muscles at the outer edges of the lens. In a fish eye, the sphere shaped lens is moved forwards and backwards to accommodate (focus). The lens has the unusual feature of a varying refractive index within it. What this does is 'bend' the light as it passes through the lens, resulting in a shorter focal length in a more compact eye, with superior light 'gathering' properties.

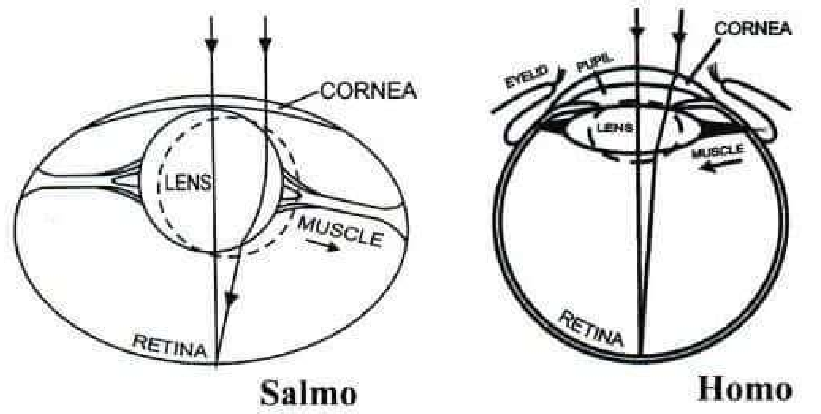


Figure 17 Comparison of trout and human eye.

Following the light entering the human eye (right), you will notice that each time refraction occurs, the lines are straight. In the trout eye (left), when the light gets to the lens, it 'bends' gradually, as the refractive index changes within the lens.

4. The depth of field of a trout eye is much better than ours, which means it can focus on a larger range of items at different distances from the eye. At rest, the eye is focused closer to the fish rather than at infinity. So, if you want to attract the attention of a resting fish, your fly had better be bright and far, or pass in front of the fish's nose.

5. Trout are able see more colours than humans. At the back of both types of eyes, there is a thin layer called the retina which contains rods and cones. These detect light and pass this information onto the brain via the ganglion cells which pre-process the information, and the optical nerve. Rods are for night (scotopic) vision and cones are for daylight (photopic) vision. In humans there are three types of cones (trichromic) for detecting three different colours. Trout have four types (tetrachromic) of cones, three for colour, and one for UV. Thus they can see a broader range of colour than humans (See Figure 18). They do not, as some have assumed, see in the Infra Red range[4].

It is commonly stated that trout have a higher sensitivity to red than humans, which is correct in the sense that the red cone in particular is more sensitive. This does not show in Figure 18 because the other cones have a broad overlap in their sensitivity, so they add up. We will go into this in more detail later. The curve for salmonids changes as fish age, with evidence suggesting that UV sensitivity may become dormant during a part of the growth cycle. Incidentally, when trout go to sea, their peak colour sensitivity moves from red to blue and green, then comes back to red when they return to fresh water.

Trout rods retract during daylight, affording them some protection against bright light. At night the cones retract, which most likely reduces the amount of light absorbed by them, so that more light gets to the rods.

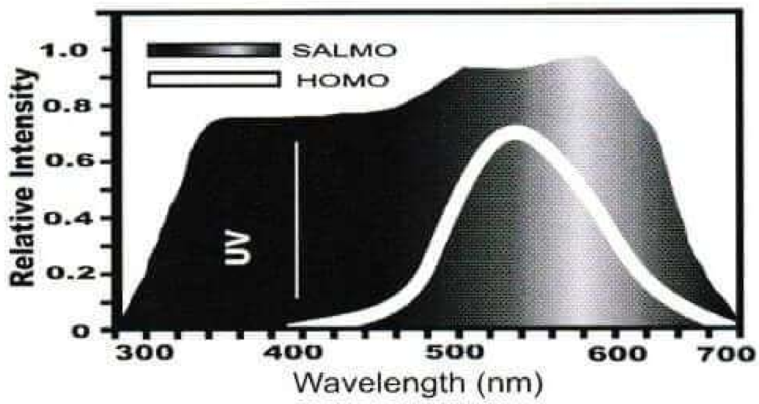


Figure 18. Approximate spectral sensitivity curve of a typical juvenile salmonid (salmo) vs. that of a human (homo sapiens) eye in daylight. Adapted from Parkyn & Hawyrshyn (2000)[5]

6. Humans, have far better visual acuity than any fish. This means we can resolve detail far better than a fish can. Although this puts the fish at a disadvantage, it has some benefit. Lower acuity means that the trout eye is able to see faster moving items better, with a reduction in motion blur[2]. This is an essential tool in an environment where things are constantly moving past at speed.

7. In humans, the cones are concentrated into a small area at the back of the retina called the fovea. In the trout the cones are grouped in such a way as to provide detail in a greater area. They also have an elongated pupil to allow better forward vision. Rods are spread out in both human and fish eyes.

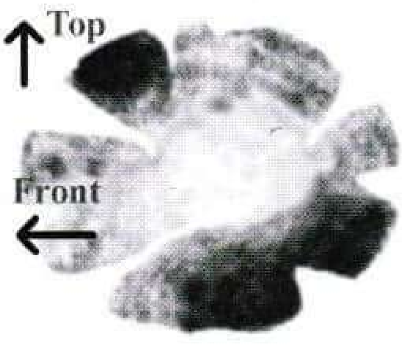


Figure 19. Rough retinal density of cone distributions in the retina of an adult rainbow trout. (from Cheng et al.[12]) Dark areas indicate higher density.

The perspective of figure 19 is of the back of the retina as seen through the lens from the outside. The density shows us where visual acuity is. Bearing in mind that an image is upside down on the retina we can see that the trout has it best vision looking up and forward, as well as down and below. Looking straight outwards, the acuity is poorer but good for moving objects.

Some authors have suggested that because trout vision is not as good as ours they would see things as a blur. This is not correct, as their visual cortex would probably only be able to interpret the available retinal resolution. This means that some finer detail would be lost but things should look 'clear' to them.[6]

Because the trout is able to see a broader range of colours, for example in the deeper blue range, that doesn't mean that things would look bluer to the fish. A white page looks white to us in the sun and under a fluorescent light. If we use a camera, the same paper will not look white under artificial light. Our brains adjust, but not the camera. The fish will make the adjustment too. The best analogy is the 'white balance' setting on a digital camera, which can compensate for artificial lighting.

The net effect as suggested by Maxfield[7] is that the extra colour (UV) provides extra range, but has the effect of reducing the number of colours in total. In other words the colour range is bigger but the steps between different hues are also bigger.

8. Another unique feature of trout 'eye' is the pineal body on top of the brain. This detects light through a transparent area on top of the head. This 'third eye' mainly functions as a melatonin regulator and day / night sensor, and has been demonstrated to be essential for controlling the skin colour for breeding and camouflage.

Fade to Grey (dusk)
Vision at dusk is termed mesotopic, and uses both rods and cones. It is during this time that the eyes adapt from day to night (scotopic) vision which takes about 20-30 minutes. As we have seen previously, even at sunset the light level has already drastically reduced. While our own vision adapts a bit quicker, the debate as to who has the advantage at dusk (fish or human) is unlikely to come up with a clear winner. Some authors have suggested that the fish are vulnerable during this period and thus nervous, but anecdotal evidence suggests that a lot of fish are caught at dusk. This is probably because they are more active, and are likely to move closer to the surface, as there is more available light. There, they may also feel safer from predators as the general level of light is lower.

See you on the dark side of the moon (night vision)
Considering that moonlight is a million times dimmer than sunlight, and starlight even dimmer, night vision will not be as easy as day vision. Night vision (Scotopic) using rods, is mono vision. Call it black and white, greyscale, light and dark, whatever helps you understand this. Trout have the added benefit of a visual feature called border enhancement (see figure 7). Because night vision is monochromic, it relies on contrast rather than brightness. This is very important to remember when designing flies to be used at night. Take special note of the contrasts between the colours in figure 10.

Incidentally, fish eyes in general are four times more sensitive in the dark than human eyes (F-1 vs. F-2), with brown trout having much better night vision than rainbow trout[4].

Smoke in the water (haze)
One more advantage fish have, is to be able to see better through hazy water than we can, and especially better than a camera can. When we place a lens (or our own eyes) underwater, the haze created by the backscatter of light becomes quite apparent. In fact, we can look

down into water that looks perfectly clear, but put on a mask and get in, and it's an entirely different matter. Clark & Goddard[14] maintain that trout in chalk streams cannot see really far (max. 10 feet) even though the water looks clear from above. This is because particles of chalk are reflecting light back at the fish. The problem is that they are looking at this from a human eye (and a camera) perspective. The fact is that trout can handle turbid water and light scattering far better than humans and are thus able to penetrate this haze far better.

The amount of haze also depends on where the sun is situated, as maximum scatter would occur with the sun behind the fish. Haze reduction can also be achieved by sitting in shade and looking into the lighter areas, as looking from a bright area into a shaded area doesn't work. Fish not only find shelter from predators in dark shaded areas, but can use them for better visibility.

Mirror in the bathroom (window & mirror)
Much has been written about the mirror and the window so it doesn't need repeating, and a quick summary will do. As a result of refraction, there is a roughly circular 'window' to the terrestrial world above the fish, which follows the fish around. It provides a distorted view of what is outside (Figure 8 & 15). This 'window' gets smaller when a fish is near the surface and bigger when it is deeper. A bigger 'window' does not mean the fish can see more of the outside world. Outside the boundary of the 'window' the underside of the water surface appears as a 'mirror'. The interface between the 'window' and 'mirror' is loosely defined and there is some vision through the mirror and reflection within the window. The smoother the water the better these are defined, and under good conditions a rainbow separating the two can be seen. See figures 11, 13 and especially 15.

According to Marinaro[11] and others, trout will rise to a dry fly in such a way that always places the fly at the edge of the window, 'locking in'.

The fish is able to see the dimples on the water created by the fly (or any part of the fly sticking into the water) at a distance. As the fly gets closer to the window, the fish will also be able to see the top of the fly in the window (see figures 9 & 11). It will then be able to line up the fly in its binocular vision allowing it to judge the distance. Once the object gets too close it will be hidden by the nose.

It is important to note that at night the mirror will not be reflecting any light, and so will be completely black.

A 'short take' myth has been blamed on the fish trying to eat the reflected fly in the mirror, rather the real one. This is impossible, as an object close to the fish will be in the window. Another popular myth is that the fish cannot see anything below a 10° angle from the surface. Thus you are able to creep up to a fish if you stay low. This has been well debunked by Hanneman[15] who clearly demonstrated that an angler is visible below that 10° angle. Something else to bear in mind, is that if we apply Snell's and Fresnels' laws, we will discover that light hitting the water at the extremely low angle of 5° from the surface, allows more than 40% of that light into the water (under laboratory conditions).

This doesn't actually prove that the fish will be able to see that light, because with a protractor I discovered that 'on paper', this light cannot enter the fish's vision, due to its angle of refraction. It is out by a fraction of a degree. But Hanneman and figure 15 show that it is possible. Why? The answer is that there are no 'perfect' conditions; water is never still or absolutely flat. On the other hand, were Hanneman's experiments flawed by something simple like the meniscus effect? Whatever the answer is, water is fluid, it moves and changes, it ripples, it waves, it bulges over obstacles, causing the angle of the surface to change, and that's the most likely reason fish are able to see those low-down angles.

Figures 9 and 11 show flies in the Mirror / Window interface. The underwater sequence in figure 9 (from top to bottom) shows a fly drifting towards the fish, approaching the mirror window interface.

In the first image, the fly is still in the mirror area and the sunken part of the fly is clearly visible. Also visible is the top part of the fly sticking into the window due to refraction. The second image shows it closer to the interface, with more of the top showing in the window. The reflection of the sunken part in the mirror is quite clear. In the third image, the fly is just into the window, and the whole fly is visible. Note the rainbow effects (Snell's Circle) at the interface, as well as the distortions created by parts of the fly as they penetrate the water. Consider how these may affect the polarisation of the light entering the water at this point.

Things look better in black and white (contrast)
Fish and other vertebrates find the differences in the luminance of parts of objects, *contrast, more important than their 'brightness'* (absolute luminance). The simple reason for this is because they need to identify objects under varying light levels. The property of an object is seen, not the lighting conditions[1]. Thus fish can see contrast (patterns or shades) very clearly. This then becomes an obvious tool when designing flies, especially for turbid water and low light conditions.

Figure 10 gives a good indication as to which colours work for contrast by comparing the colour with the B&W. At night flies are generally seen against a lighter background (the sky) unless fished deep. 'border enhancement' also comes into play and can help increase contrast.

Part 3 - COLOUR

"*Your Majesty is like a stream of bat piss....... I, um, I, ah, I merely meant, Your Majesty, that, ah, you shine out like a shaft of gold when all around is dark.*" - Monty Python

Neon lights (fluorescent colours)
Earlier, it was briefly mentioned that *fluorescent colours*, convert not only UV light into colour, but any colour with a wavelength that is shorter than itself. To work it out easily, refer to figure 4, and always make the fly colour to the right of the water colour. This is the easiest way, not only to provide brightness to your flies, but to get red and orange at depth, where they are usually absent or reduced. Essentially you can create colours underwater that don't naturally exist at that depth, making it a handy tool for turbid conditions. For

example, a red fluorescent material can be 'lit up' by green light, but not the other way round as the red light is 'longer' than green (see figure 5). Using this to your advantage, you can also increase the brightness of your fly at depth.

The most visible fluorescent colour would be one that is one with a colour slightly to the right of the dominant water colour (longer wavelength) and will not look out of context to the environment. Thus for green water, yellow would be best.

Come on baby, light my fire (phosphorescence)
Material that glows in the dark will certainly get the attention of a fish at night. Whether it is good attention or bad is up to you to decide. Anecdotal evidence from 'down under' suggests that it works well, and is popular in the region. Think of phosphorescence as fluorescence with a time delay. Its biggest weakness is that it needs continual 'recharging' as it fades fast. Charging with a UV light is popular, but that may be because of the misconceptions around fluorescence.

Isn't she a Starling! (structural colours)
Colour is a fascinating subject, and mixing them even more so. When we mix pigmented colours (like paints) we get one result. Mix those same colours using light, we get a different result. Mix the two and you get another result.

Figure 5 shows the effects of mixing combinations of pigments (paint) and light. Blue light onto red paint does not reflect any colour as there is no red light in the blue to reflect. Red light onto blue fluorescent paint does reflect anything either as the red has a longer wavelength than blue (see above). When blue light shines on red fluorescent paint, it reflects red. This is because the blue light has a shorter wavelength, which can 'activate' a fluorescent colour.

There is another important way of producing colour called *structural colour*. Bird feathers are great producers of structural colours; think of the shiny blue on a black starling, the bright green and red on a sunbird or the bright colours of a peacock feather. These are all structural colours. There are also hairs like mole hairs that can produce colour, the vivid colours on butterfly wings, and perhaps even the scales on seal fur. (I have not tested this last hypothesis). See figure 14.

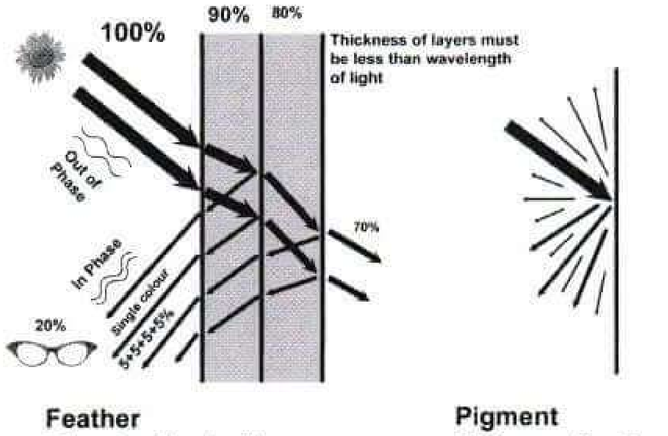
Structural colour (iridescence) is created by nano-structures in the feather or fur construction, which use the principles of reflection and refraction to produce colour.

To explain this, let's go back to the pigmented colours. White light hitting a red object has all the colours except red absorbed, with red being reflected in many directions. That allows you to see it as red. If the light is only blue, there is no red in it, red cannot be reflected and the object will appear black.

The intensity of red light reflecting back at you must be less than the light that hit the object in the first place, as all the other colours have been absorbed, and the remaining colour is scattered. To simplify this, let's assume the white light has all the colours of the rainbow in equal proportion, seven colours (it's not really like that). If only the red is reflected, that's one seventh of the light. But because it is reflected in many directions, you will see even less of the original intensity. It will look like the same colour from any direction.

You will have noticed when looking at structural colours on a bird that they are quite vivid and bright. That is because the structure is able to convert most of those colours (white light) into a single colour, which is directional and not scattered like our red example, with its inherent losses. It can also reflect different colours from different directions.

The simplest example of a structural colour is the thin film of a soap bubble, or oil on water which creates a rainbow effect. The thin boundary of refractive material causes 'in phase' light (constructive interference) to create single concentrated wavelengths.



The layer must be as thin as or thinner than the frequency of light (nm) which strikes it. Iridescent effects can be created by any nano-structures, thin layers (soap bubble), diffraction gratings (butterfly wings), nano tubes (hair) or photonic crystals (peacock feathers).

Figure 20 White light interfacing with a 'structure'. Light reflecting off it must be 'in phase' and will be a single bright (in phase) colour. It will be directional and much brighter than a pigmented colour as they 'stack up'. Compare this to the diagram on the right which shows light diffused from a pigment.

Just as we can mix pigmented colours with light to produce a different colour, structural light can be combined with pigments to create a different colour. This is common in feathers, especially those we see as blue.

Silver is a structural colour that is reflecting all colours and gold the same, but without blue.

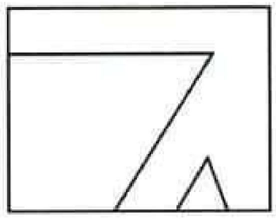
Part 4 - USING COLOUR

Fairground Attraction (Fly Visibility and Attractive Powers)
Dick Walker[8] has little time for exact imitation in flies, and for good reason. He cites an experiment with butterflies, where several versions of artificial females are presented to males. The males chose an artificial bigger than the natural and with simpler colours (and a real flapper), over the closer imitations. He suggests that the (real) butterfly female may have evolved as a compromise between attraction and camouflage.

The second point he makes, is that **if insects were designed to attract trout, they would be extinct!** So he asks "*What characteristics can be exaggerated... without destroying them as points of recognition*" and answers that the "*most obvious is colour*". The following is a different take on his idea.

Figure 21 (left) on the left is an instantly recognisable symbol for food, even though there is no plate, or morsel of food in sight. If you were the subject of a Pavlovian experiment, you might even start drooling right now.

The 'droodle' on the right (figure 22), is not as obvious (unless you are a Frank Zappa fan) and it will most likely have to be explained to you. You want your fly to be like the knife and fork, instantly recognisable to the fish as food, not the droodle.



To achieve this you can *exaggerate* recognisable points (make a caricature) of a fly to make it more attractive. It does not have to look like the natural, as missing or extra items can make it more attractive. You do **not** want to have to explain to the fish that your offering is food. It will be ignored, because you can't explain anything to a fish. Walker points out that "*given enough points of recognition, a trout will ignore points of difference*".

He goes on to state "*[when fish are] preoccupied [with] eating one item, [we] need to imitate with something that has characteristics that the fish regards as food at that time [and the] most important is colour. Some exaggeration of the colour and movement may increase the attraction....to the extent that it may be preferred. A selectively feeding trout is looking for points of similarity [positive] or points of difference [negative].*"

Also bear in mind that trout have been known to inspect a natural for quite a while before taking it, and also sometimes reject naturals altogether.

I'm too sexy for this fish (Colour and the Fly)
How visible is colour to fish? This depends on the water and lighting conditions as discussed previously, but also depends a lot on what kind of fly is being presented. Dry Flies are mostly on top of the water, Emergers are both in and out of the water at the same time, and Wet Flies and Nymphs are under the water.

The direction of the light and the position of the fly in relation to the fish also need to be kept in mind. A fly in silhouette will not show its colours well.

1. Dry Fly. The fish should first see dimples on the water surface in the mirror, or the effects thereof. Next, its wings or hackles will show through the window, unless the fly has drowned somewhat. The points of light around the hackle dimples are more likely to show the background light colour than the colour of the fly. Next would be a full view of the fly and its body between the mirror and window. Thereafter the fly will be quite visible, or just a silhouette, depending on the lighting conditions.

Clark & Goddard[14] maintain that many trout never see the body of the fly that catches them. They (and others) disagree regarding the importance of colour in dry flies. They are of the opinion that the "*prime requirements [are] feet dimples, correct size, silhouette, and to a certain degree, translucency*".

LaFontaine[16] believes that everything has to be right, including body colour, especially for a fish that may be following the fly. He believes that the fish rises to keep the fly in the edge of window where it can see its colour clearly.

2. Emergers. The colour of an emerger body can be clearly seen underwater, and then the hackles as the fly moves closer to the window, then the full view in the 'window'. A fish should be able to see an emerger from a good distance. Emergers are also usually a popular food, as they are vulnerable, thus 'available'.

3. Wet flies and nymphs. Like the emergers, their colour is quite visible underwater, but the colour visibility could be enhanced or retarded depending on depth relative to the fish, and the water and lighting conditions. Sholseth[17] believes that colour is less important than luminosity, as cone mosaics in the trout retina function first to create target enhancement. This is debatable, but certainly applies to low light conditions when colour does not show well.

Simply irresistible (Key or Trigger Colours)

"Each species of insect possesses [but not obviously] a colour by which trout recognise it ... by incorporating [a] key colour [the] artificial can be made more attractive" - Walker[8]. He qualifies this by stating that he is not suggesting that the absence of key colour will render a fly useless. He also names a few examples, one of which is the Iron Blue. This is a small, dark, slate grey, *Baetis* mayfly to which he allocates the key colour of crimson or magenta. The Snipe & Purple fly is a popular imitation of a drowned Iron Blue, and like Walker's example has a body (purple) that does not match the natural. More about this in fly design below.

I can see clearly now (Visibility of the Fly)

Before you can try and convince a fish that your fly is food, you need to get the fly where the fish can see it, and has enough time to intercept it. Remember that the fish's eye is myopic (short sighted) when at rest, so you don't want to be too far so that it doesn't see it. The fish may not be prepared to move far either.

LaFontaine[16] believes that bright flies are required for flat water, and dull for rough water. This makes perfect sense as a sparkly fly will have its sparkles lost amongst bubbles in rough water, so a dull fly will stand out. The converse applies to flat water, where a dull fly will not 'stick out'. He also maintains that during hatches fish look for clusters of brightness on the surface. There is a rider to his bright fly suggestion, which states that a bright fly should be avoided on cloudy days. (You've got me there, Gary!)

One needs to note that bright materials obscure colour and the outline of a fly. This applies especially to dry flies on broken water, but also applies to sunken flies.

An important consideration is the fly position in relation to the fish. The fly will either be situated above, below, in front of, or next to it. This needs to be considered, as it affects whether the full colour is seen, or a silhouette (or a combination), and which part of the fly is visible (top, bottom, front, back, side).

Also consider where the light is. If the sun and fly are in front of the fish, the fly will be a silhouette or even invisible. If the sun is to the right of the fish, a fly on the right will be a silhouette. A fly presented on the left, would then be visible in all its coloured glory. When a fly is backlit, the edges on lighter colours are fuzzy, while black provides a clean sharp line. Thus black adds to effectiveness in silhouette, and white the opposite.

Just in case you haven't figured out figure 20, a similar drawing by Roger Price features on the cover of Frank Zappa's "Ship arriving too late to save a drowning witch" album.

Karma chameleon (Colours, Combinations and Materials)

In the previous section we mentioned making a 'caricature' of your flies in order to stimulate the 'eat' response in fish and emphasised the importance of colour. You should also have a good idea about how a fish sees things, and recall that it has vision in the UV range and is able to at least sense polarised light.

Before we examine individual colours, we need to note that many studies have been done with regard to which colours fish prefer. Food preference tests have been done using coloured maggots, pellets, and roe, as well as testing the colour preference of refuge areas[18, 20].

The most popular food colour is **blue** followed by **red,** then **black** and thereafter orange brown, yellow and green. An important point to note that is the roe tests showed that some colour combinations were preferred to single colours[21]. In daylight, combinations of yellow/ black, and yellow/blue were preferred. In lower light the preferred combinations were yellow/red/ and blue/black (see Figure 10)

Please note the following: 1. Visibility does not equal attractiveness. 2. Material colours change (usually darken) when they get wet. 3. You are 'selling' your flies to fish, not anglers.

Blue is a scarce colour in a freshwater environment and is rare in insects, but for some reason trout love the colour. It appears a lot in attractor patterns, so don't be shy to use it because it's not a 'natural' colour.

Jay feathers which are blue are an essential colour for the hackles of 'loch style' flies. Just bear in mind that the majority of blues in feathers are structural colours or mixed pigment and structure, and are seen differently by the fish. Thus a dyed blue material may be inferior, or less effective.

Red has always been a popular as a 'trigger' colour, probably because it works. Despite being attenuated quickly at depth, it's a colour used by spawning fish, which emphasises its importance. Besides being an attractive colour, it's also one of aggression, and also the colour of blood.

A copious amount of red light is available at dusk and dawn, which makes it an excellent choice during those times. If you need red at depth, use a fluorescent red.

Claret is the colour of good red wine, which is great if the fishing is slow (the wine that is).

It is an imitative colour of some of the adult mayflies, but you need to look at them closely to see the claret. It's a very popular colour in seal fur for a lot of wet flies, and is said to be very effective.

Black is the big contrast colour, visible during the day and at night. It can be used liberally, but is more effective 'diluted' as in when mixing red or grey into black dubbing (especially in dry flies). Mixing also gives it a degree of translucency. Natural insects are not usually black, but rather a dark shade of brown. Keep in mind that black may be more effective in combination with yellow or blue.

Orange is a popular bright trigger colour, especially for still waters. For dry flies it's useful in a more muted version for body materials. It is Walker's colour for the Blue Winged Olive and Pond Olive.

Brown is the perfect colour for brown waters, as the insects in that water will tend towards brown as camouflage, so fish will be looking for brown food. Dark brown is also an alternative colour to plain black as it will look more natural (see Black) Chestnut brown is also a popular colour in 'Olive' imitations.

Yellow is regarded by LaFontaine[16] as a 'danger colour' to fish (as in Bees and Wasps), unless there are constant hatches of yellow insects. However, popular flies like Stimulators and Hoppers have yellow and have proved effective. Also, the previously mentioned studies show that a black and yellow combination is popular. Primrose yellow is the colour of choice when imitating the Pale Winged Dun and the Caperer Sedge, a mottled brown caddis. Pale yellow is recommended.

Green is a colour abundant in sunlight and will show well on a bright day. LaFontaine maintains that trout in tree-lined streams respond better to green flies than in other streams. This makes sense for two reasons. One, there would be a lot of green in the light due to the vegetation which would show off the green in the fly. Two, with green leaves abundant, there will be a lot of green terrestrials. Green is Walker's choice for a yellow spotted caddis and for crane flies, none of which have any green in the natural.

White is LaFontaine's choice for dry flies in shadow. It has the ability to take on the ambient colour, which is useful, and is obviously more visible in the shade or indirect light. It is a bad colour for shape however, so making an outline with white will not work.

Violet and Purple are colours that border on the UV range. They are reasonably quickly attenuated by water, but are still useful at depth, and highly visible to fish.

Colour combinations have been covered above, but as a reminder, here are the most popular ones, in order, Yellow/black, Yellow/blue, Yellow/red, Blue/black

Polarising materials (PM) and their use is still highly debatable, along with the extent of polarised 'vision' in trout. But some facts remain. Water polarises light and so do insect wings, so the use of a polarising material like stretched cling film may be quite attractive. Fish may use changes in polarisation of the underwater light to detect prey, as the prey themselves disturb or reflect the somewhat evenly polarised light.

Contrast is very visible to fish, whether in patterns or shades. Certain colour combinations provide more contrast than others (see colour combinations above), making them more visible. Speckled feathers have good contrast, but because of the fineness may not be as visible to the fish compared to us. Black and white is another combination that provides high contrast, making a fly visible from far.

The most important aspect of contrast is its use in low light conditions, when a trout's vision moves to scotopic (mono coloured night vision). Fish may also use contrast to find cryptic prey by finding their shadows in good light.

Camouflage is an important aspect to consider when designing flies or fishing them. Prey items will try to look like the background, taking on the background colour, so don't use a camouflaged fly out of context! As shadow is camouflage's curse, you could consider using reverse counter shading on your flies to imitate a shadow. A static camouflaged fly is going to get you nowhere, so remember to build in movement and fish with movement. The best thing about camouflage is that works to your advantage. A fish does not expect to see a perfect insect as the insects try to break up their outline, so fish are unlikely to expect a perfect fly. This may explain the popularity of 'buggy' flies "*certain objects are associated with certain backgrounds, and if the background [or context] appears odd ... alarm bells ring.*" Parker[2]

Materials have a significant effect of fly design and appearance. Synthetic materials tend to keep their colour better when wet, while natural materials get darker. Keep in mind that certain natural materials will have an advantage over synthetics in some applications and vice versa. Naturally coloured materials are better than dyed materials. For example; blue or black feathers may be combined pigment and structural colours, or just a structural colour, which will be impossible to match using a dyed feather.

Ultra Violet (UV) reflecting, or producing materials are useful, as many prey items reflect UV light and, as mentioned earlier, trout have vision in the UV range.

Don't worry, be happy

You may be forgiven for thinking that fish are hyper-smart creatures that examine every detail of your fly, and that can get *preoccupied* at times.

Be not discouraged, as you know that trout do get caught, and don't in fact require exact imitations of natural insects, as they can easily be fooled into eating something not even resembling the natural. There are several reasons for this. It may be interpreted as prey, as a threat, or sometimes they just can't help having a go at it. It's your job to produce and present something that will trigger any of these behaviours.

Hopefully this 'lesson' on light and colour has helped you learn something that will help you design better flies and catch more fish. Again, remember that the fly does not have to reproduce the actual qualities of something, or be an exact imitation. It either needs to show some key trigger colours, features (caricature), or the correct movement.

As mentioned in the introduction, a fish has a primitive brain and has to focus on a priority feature or event in order to survive. So as long as you can get that 'focus' and make sure it is in context, you are in the money.

"*That'll F*** 'em*" – Ed Herbst.

Acknowledgements

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Comment on the above article is encouraged. As mentioned in the introduction, I have tried to stick with facts, but may have erred. If you found anything wrong, want to comment on any point, or ask questions; please contact me at the@sylum.co.za. Really! Your input is welcome.

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"Scientific information indicates that the human eye has about 14 times the resolving power of a trout's eye (Byrnes, 1990). The fish's poor ability to resolve detail is the reason that we can get them to take our flies.

"The trout's eye can detect relative size, overall silhouette (shape) and colour patterns. In addition, the fish is highly sensitive to the behaviour of its food organisms.

"Such sensitivity can be significant in fly design: a trout may not recognise the exact shapes of a mayfly nymph's gills, but it is highly attuned to the movement of these appendages."
Gary Borger*, Presentation, *Tomorrow River Press, 1995