Production and Transmission of Light

- Measurement
- Light and color production
  - Pigments, interference, scattering, bioluminescence
- Transmission through the environment
- Optimal hue, contrast, shading

Properties of light signals

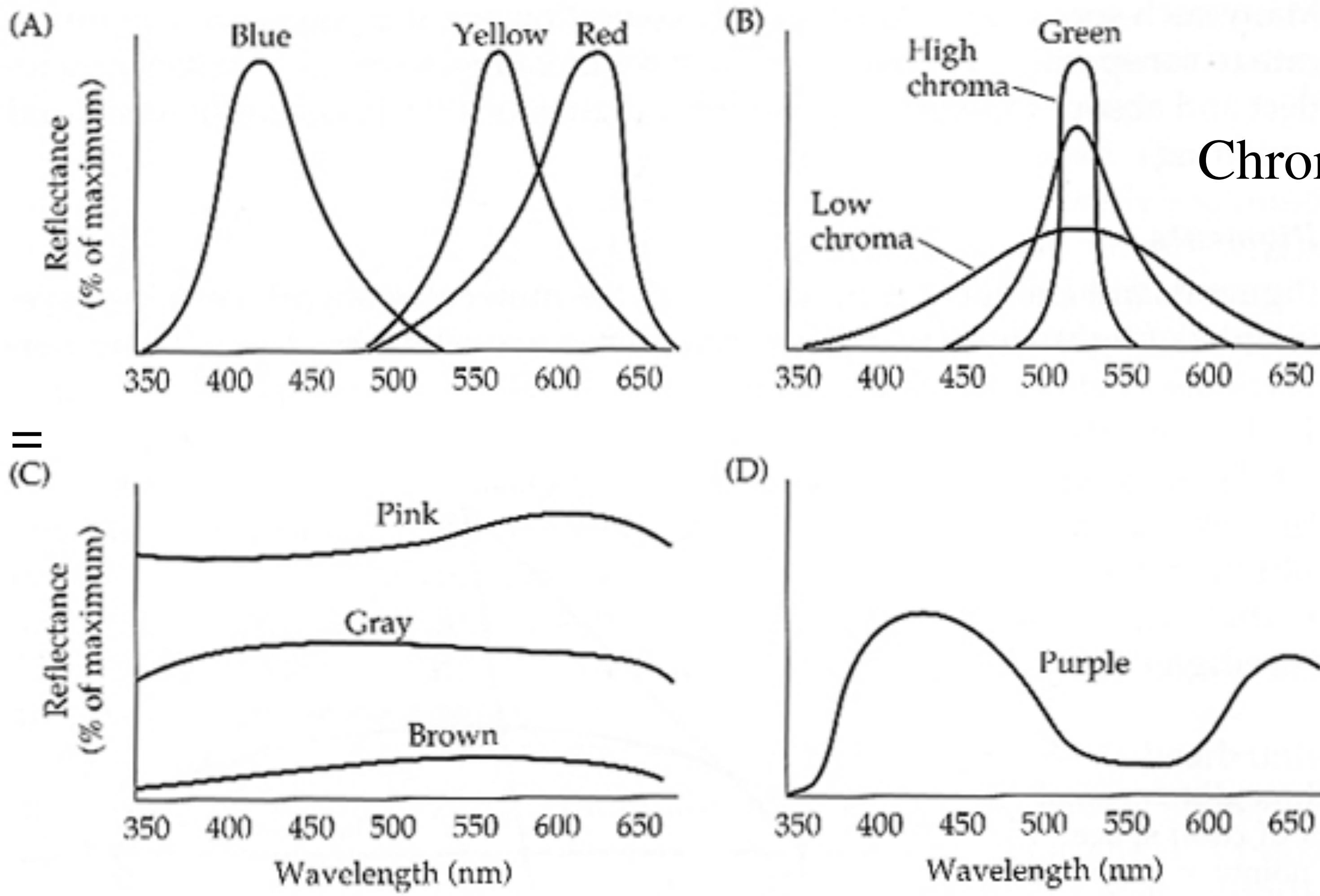
- Brightness
  - Intensity of reflected (or self-generated) light (units = radiance)
  - Function of surface structure and range of wavelengths reflected
- Spectral composition (color)
  - Hue (dom. wavelength) and chroma (saturation)
- Spatial characteristics
  - Size, shape, color pattern of body structure
  - Position and posture of sender
- Temporal characteristics
  - Variability in the above characteristics

Color Spectra

Hue

Chroma

Brightness = Intensity



Color

Color results from selective absorbtion/reflectance

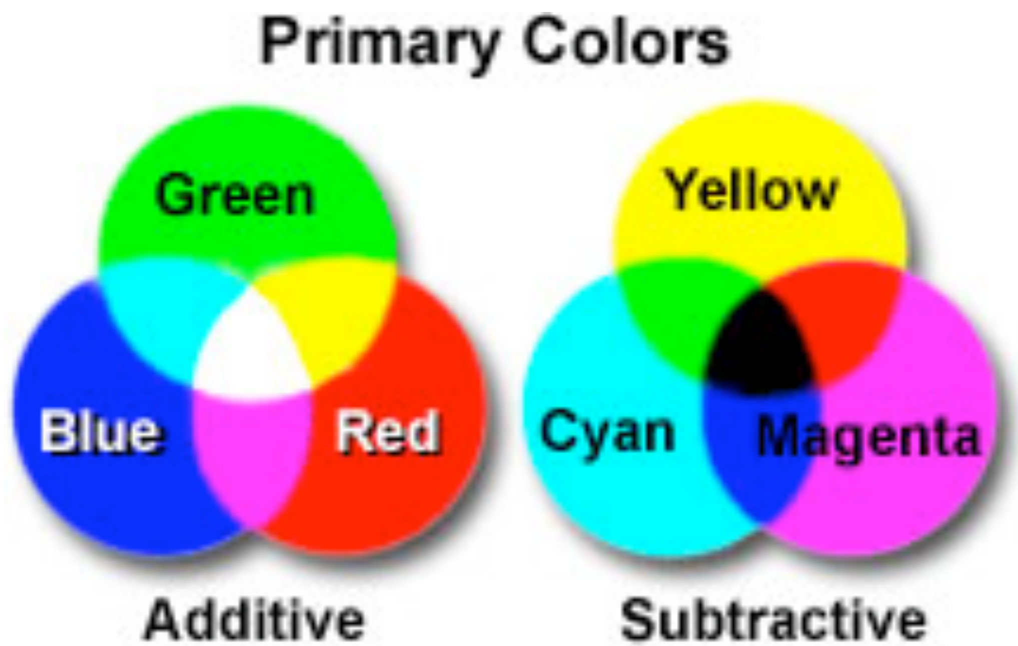


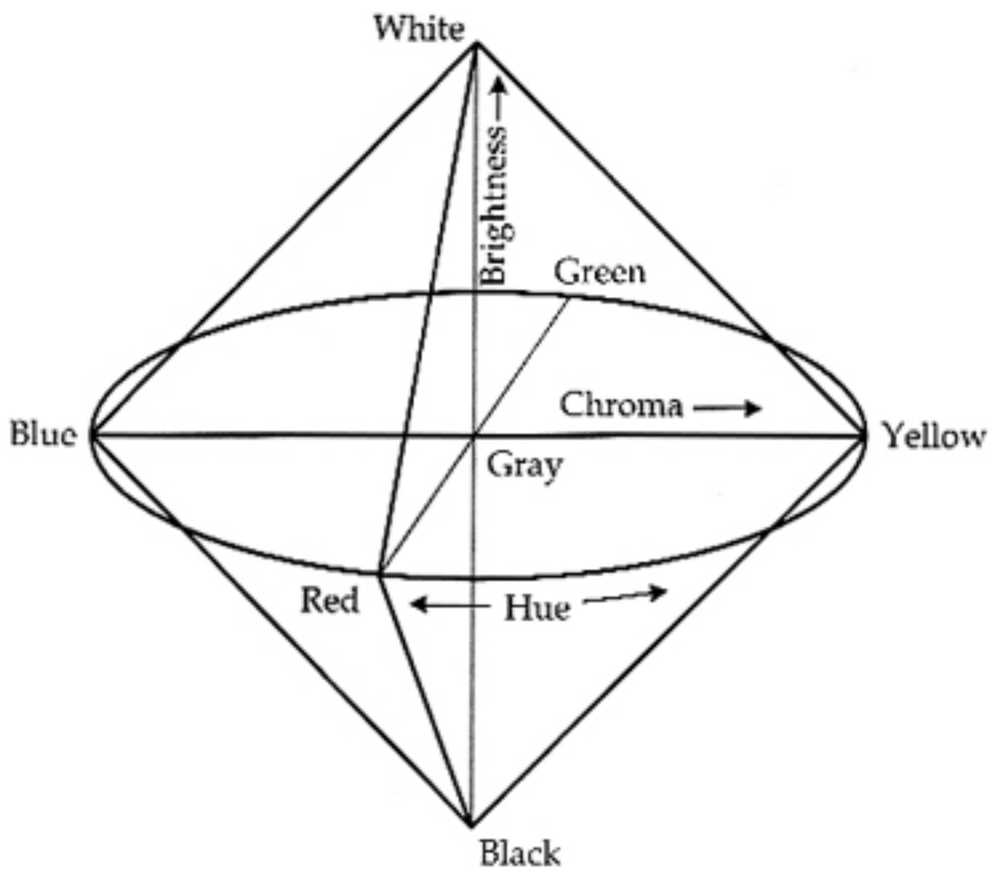
Figure 1

White = all colors reflect

Black = all colors absorb

Color has 3 dimensions

Color systems are based on human color perception



Brightness = radiance

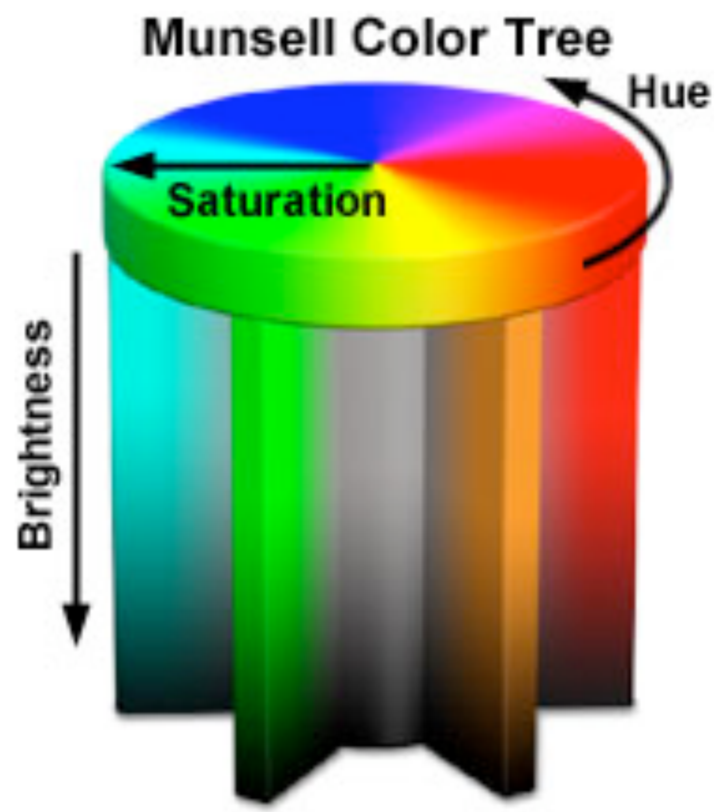
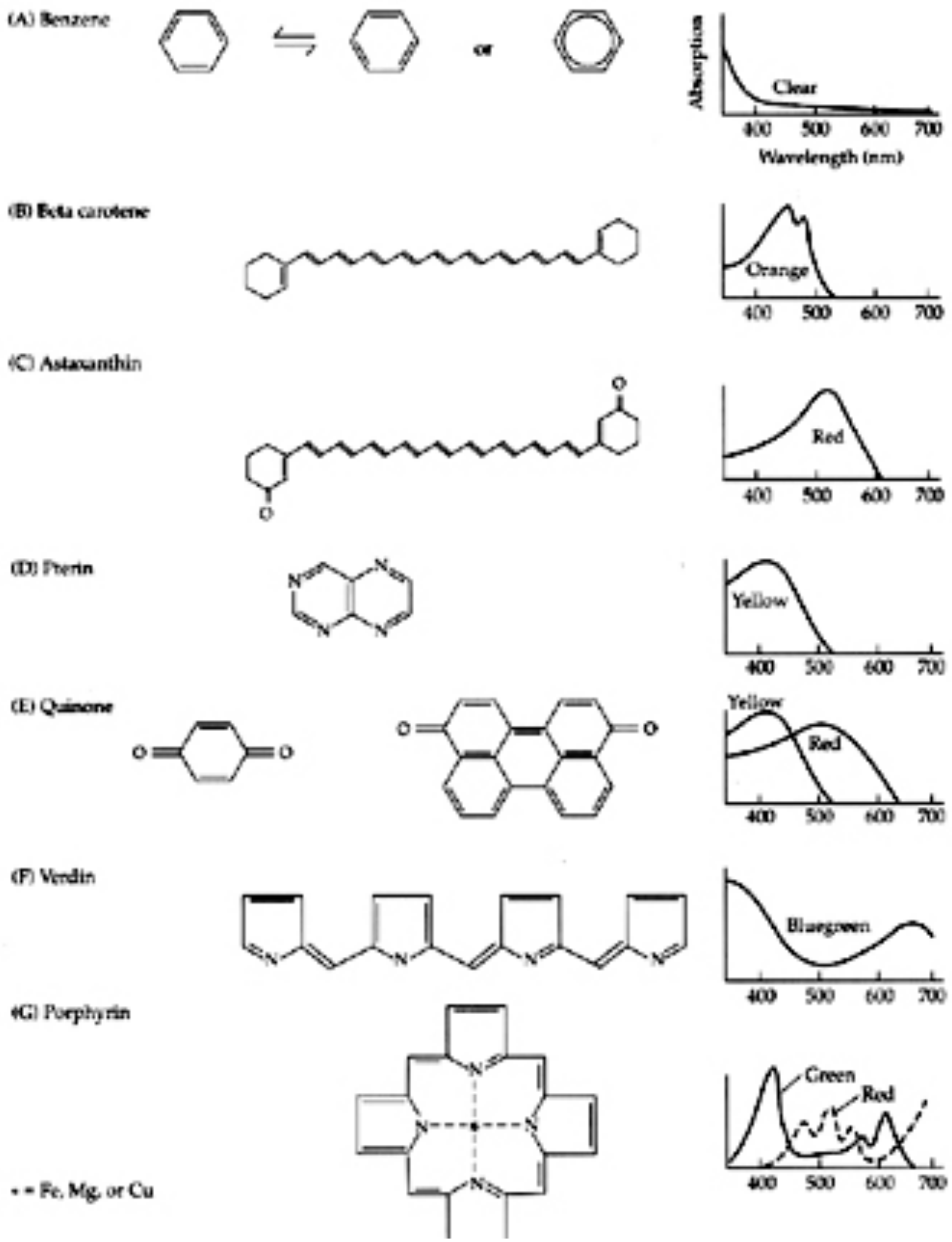


Figure 3

Sources of color

- Pigments
  - Molecules which selectively absorb photons of some wavelengths and transmit others
  - Size of molecule affects wavelength absorption
  - Short chain molecules require high energy (short wavelengths) for excitation
- Structural colors
  - Interference
  - Scattering

Pigments (absorbtion spectra are inverse of reflectance spectra)



Benzene absorbs UV

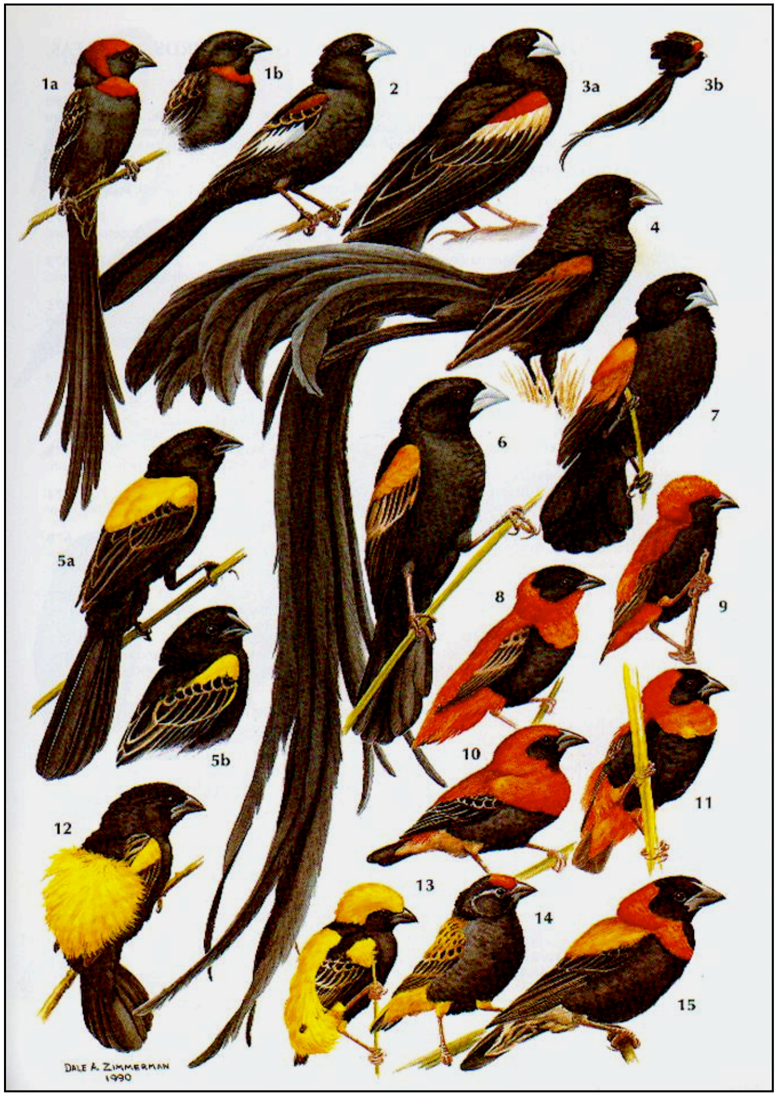
Carotene absorbs blue and transmits green, yellow and red
Come in different lengths

Pterins: yellows and oranges found in insects

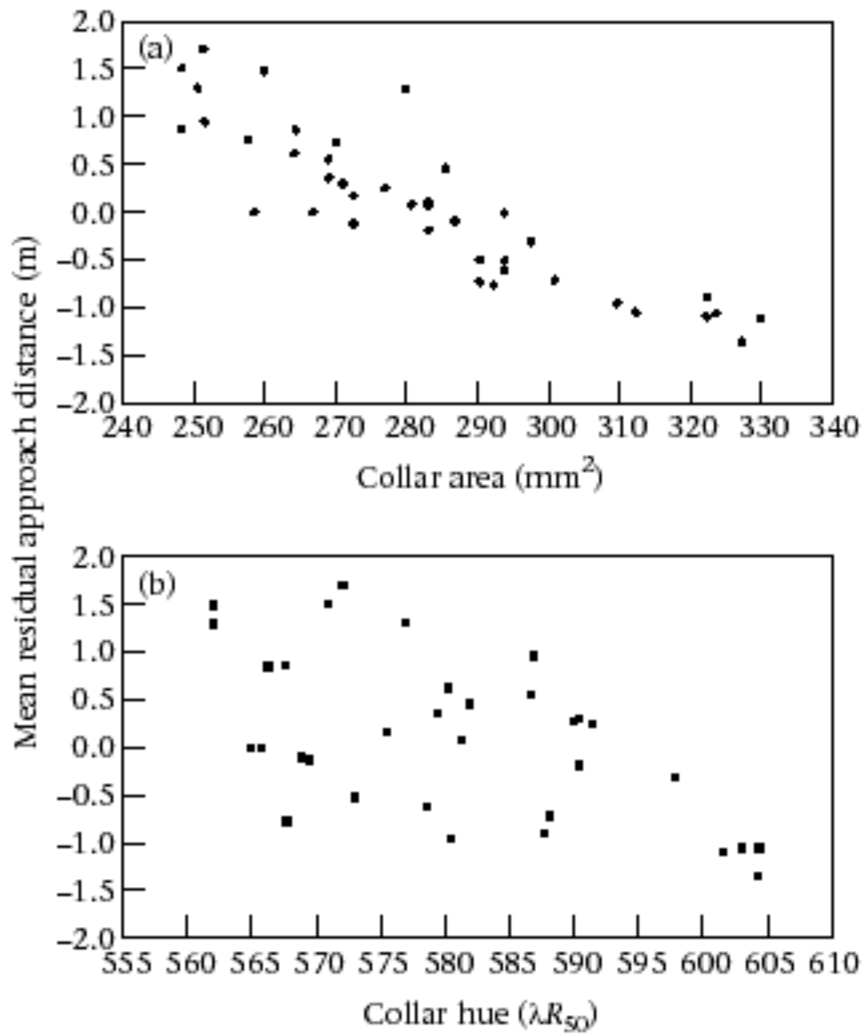
Verdins create blue-green color in bird egg shells

Porphyrins: iron = hemoglobin, magnesium = chlorophyl, copper = turacin

Carotenoids in widowbirds and bishops



Note tail vs color, comes from diet



Badges of status in Collared widowbirds
Pryke et al 2001 Anim Behav 62:695-704

Pterins

Photos from www.butterflies.com

Porphyrins

Schalow’s turaco

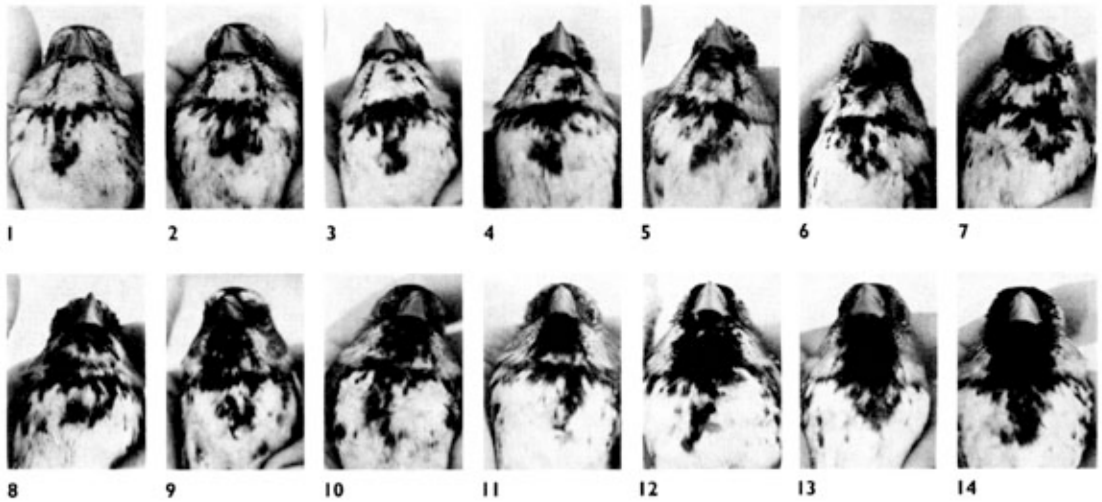
Great frigatebird

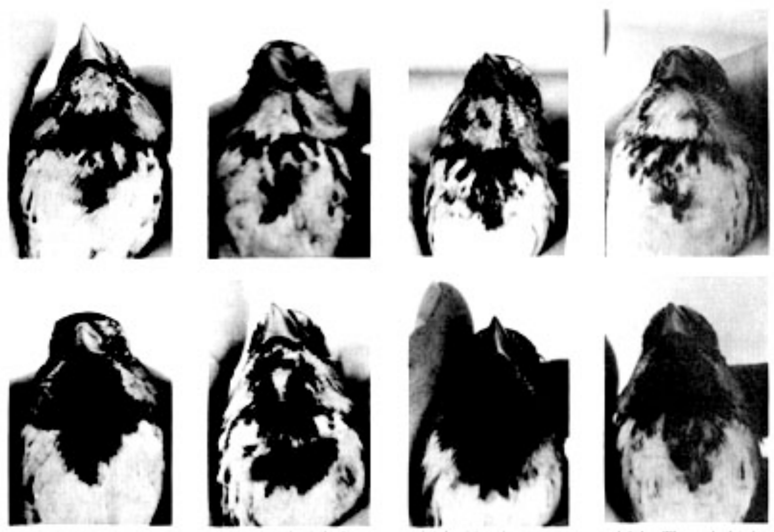
Bird photos from <i-bird.com>

Melanin and Guanine

- Melanin
  - Large protein that absorbs all wavelengths and, therefore, appears black
  - Present in skin and hair of mammals, chitin of many insects
  - Coat color variants are caused by temporal regulation of melanin production during hair follicle growth, e.g. agouti phenotype: dark-light-dark
- Guanine
  - Forms platelets that reflect all wavelengths
  - Found in fish scales, appear silver

Status badges in Harris sparrows





1 Male. He stayed in the flock but suffered a significantly higher rate of attack.

2 Female. She left the flock and travelled alone, where she tended to be attacked less often than before.

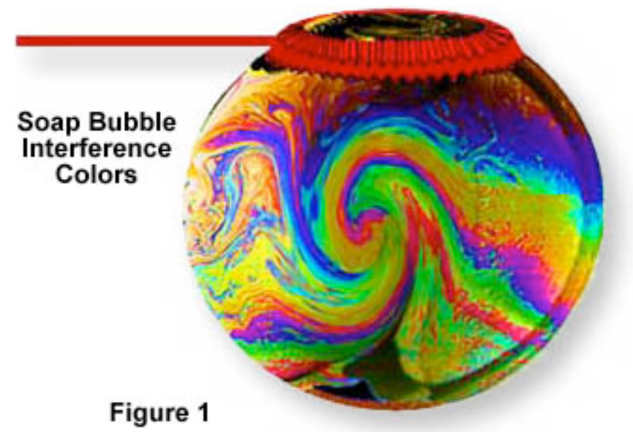
3 Male. He often travelled alone or on the edge of the flock and suffered a significantly higher rate of attack.

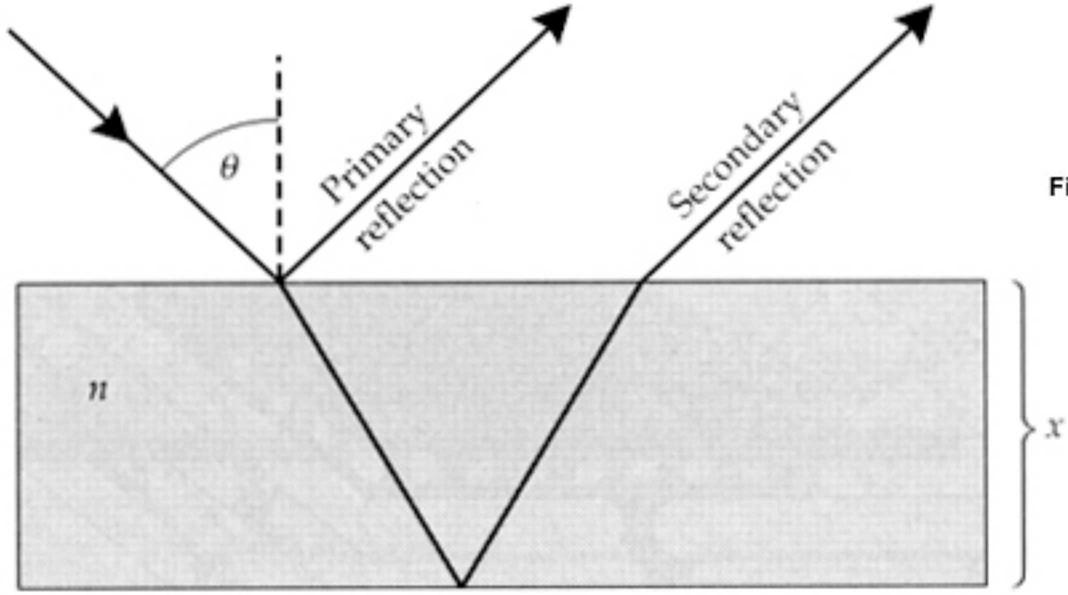
4 Male. The only bird to show an improvement in status, he stayed in the flock, where he tended to be attacked *less* often than before.

Structural colors are caused by interference

Color depends on the reflection angle from feathers

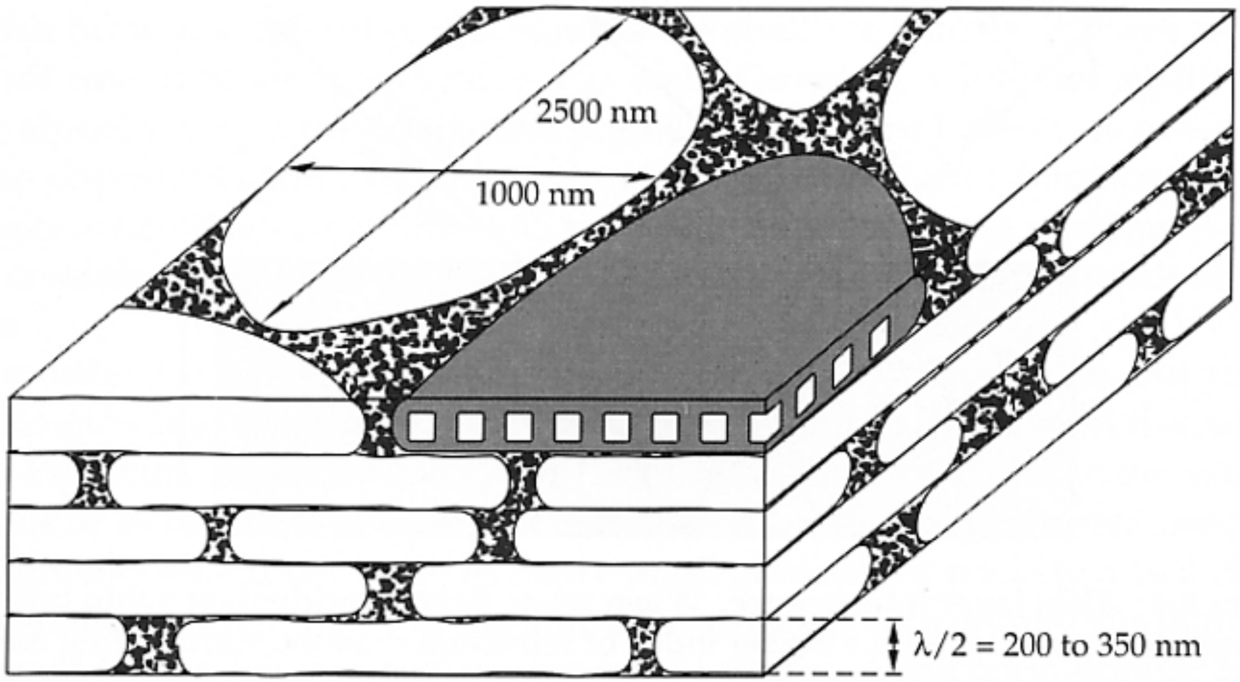
Interference





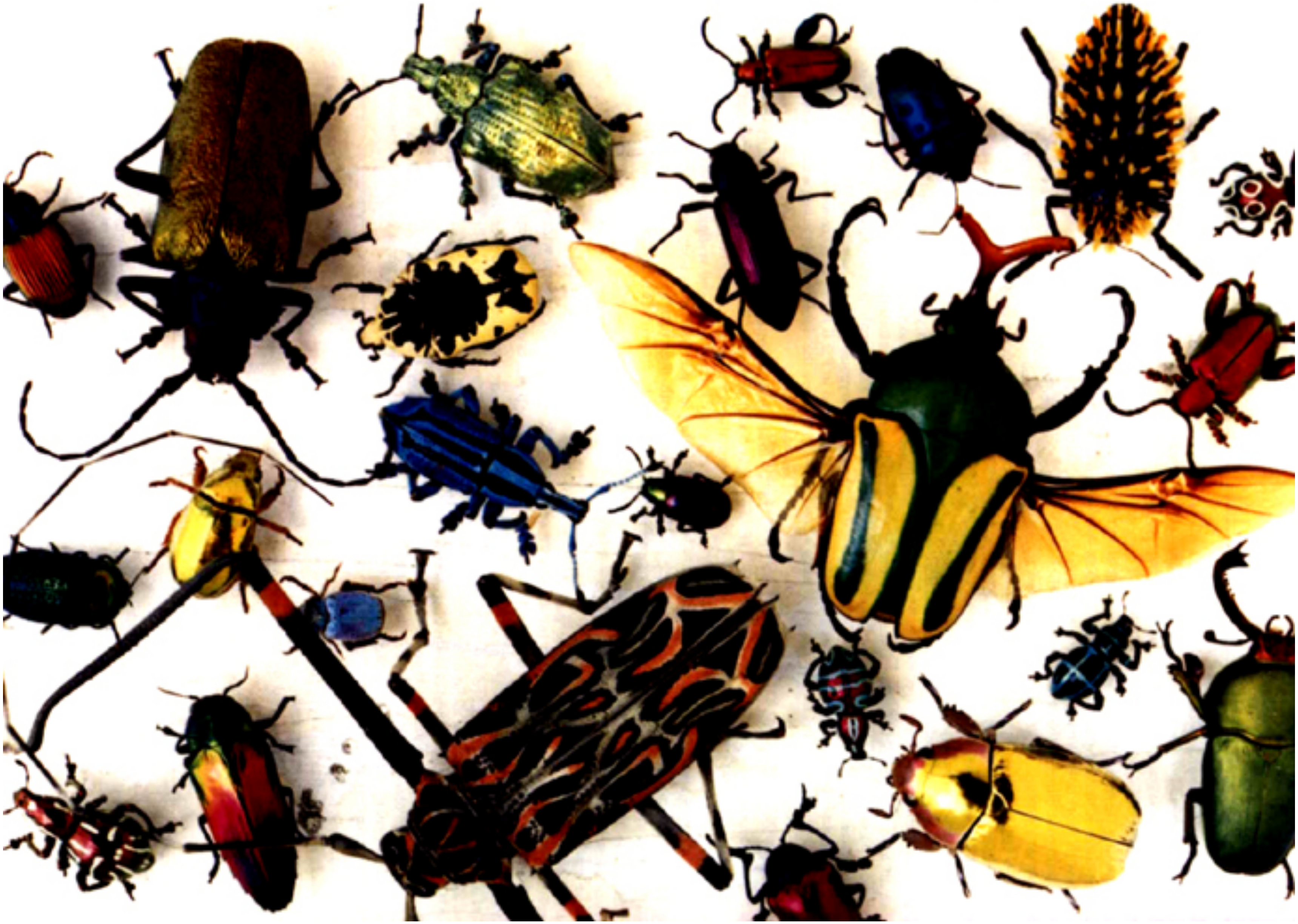
- Created by layer of wax or keratin over feather, scale, etc.
- Positive interference (waves in phase) results at a certain thickness (*x*) refractive index (*n*) and angle of incidence for a given wavelength
- Refractive layer may be underlain with melanin to absorb non-reflecting wavelengths

Interference in feathers

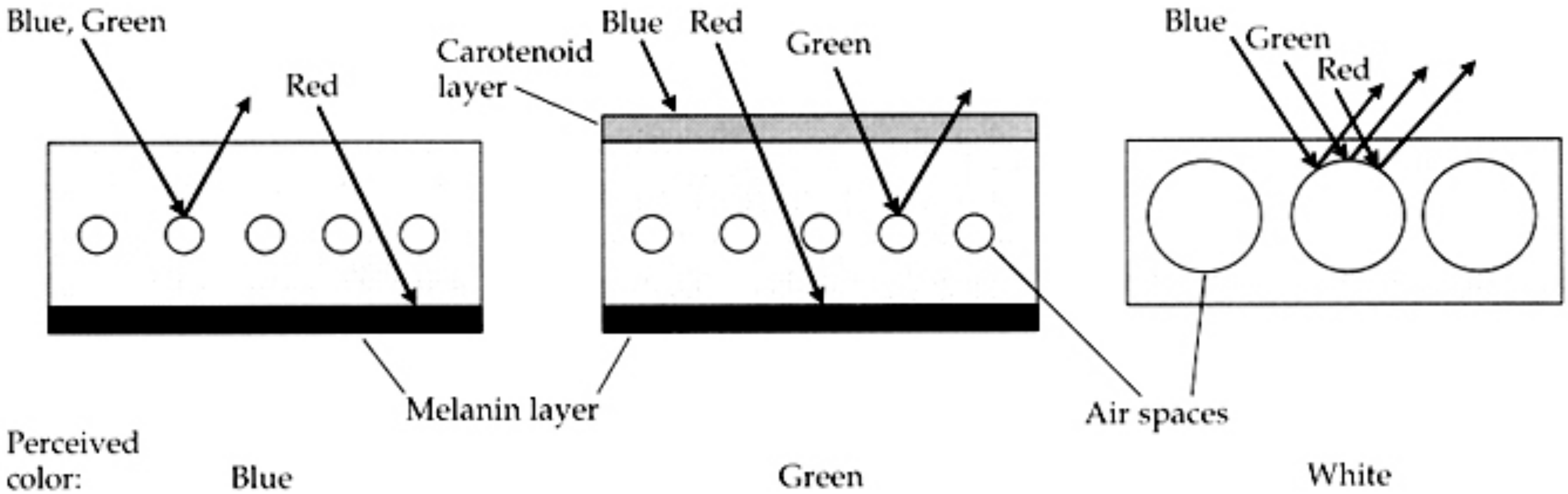


- Constructive interference enhanced by stacking refracting layers
- Found in hummingbirds and peacocks and some butterfly wings

Beetles coat melanin with wax



Color by Scattering



Mutant color type

Wild-type

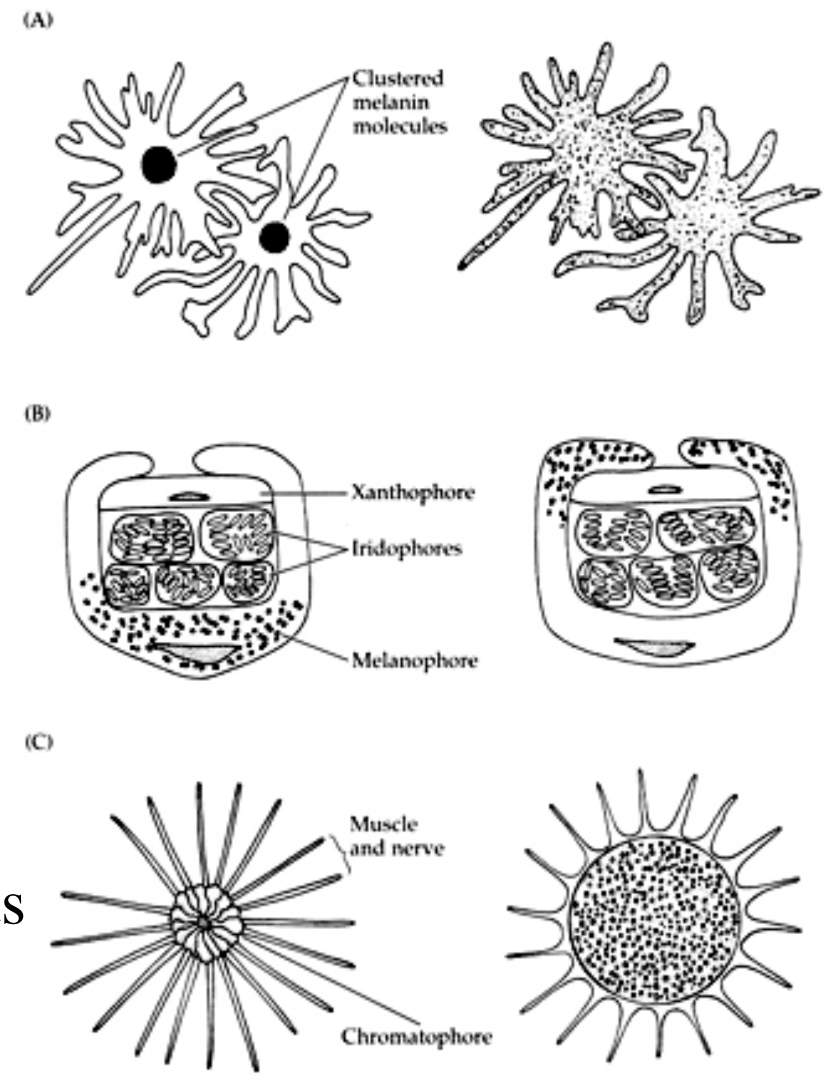
Mutant color types

Temporal modulation of color: chromatophores

Fish

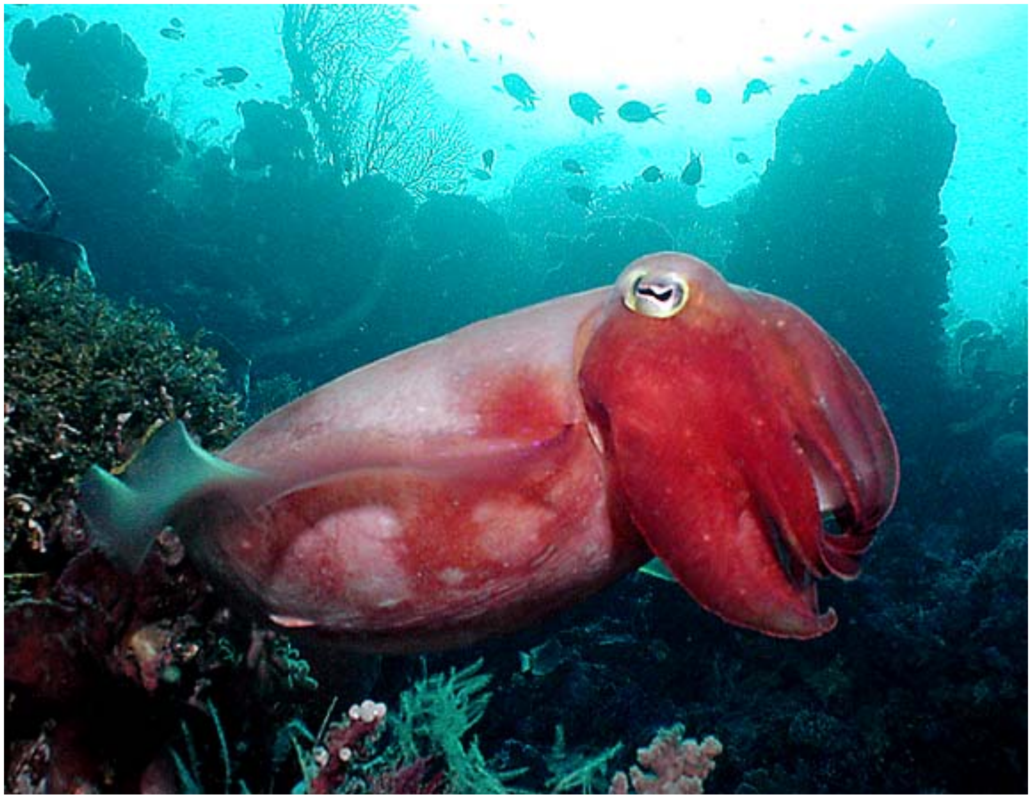
Lizards

Cephalopods



Iridiophores contain platelets that reflect some wavelengths

Cuttlefish have chromatophores



Chameleons can change color

Temporal modulation of color: bioluminescence

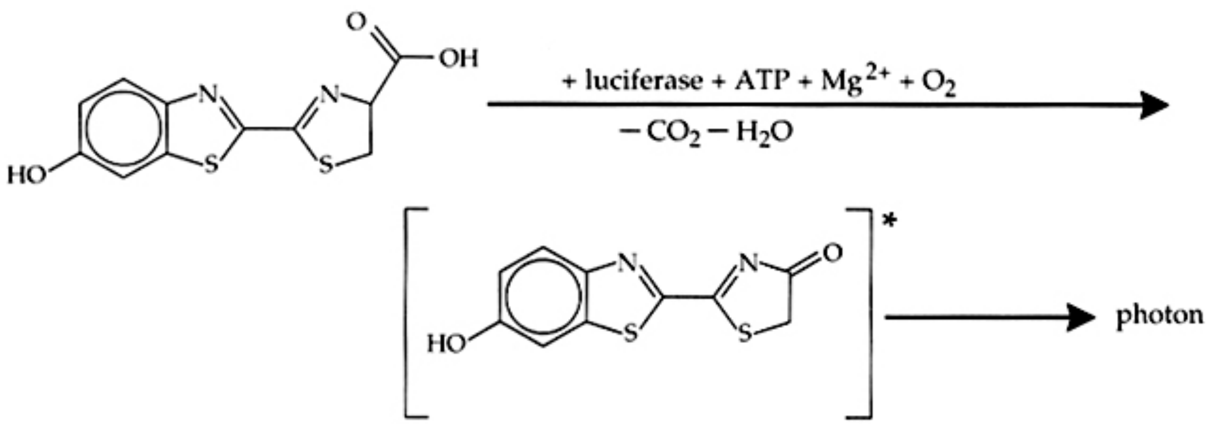
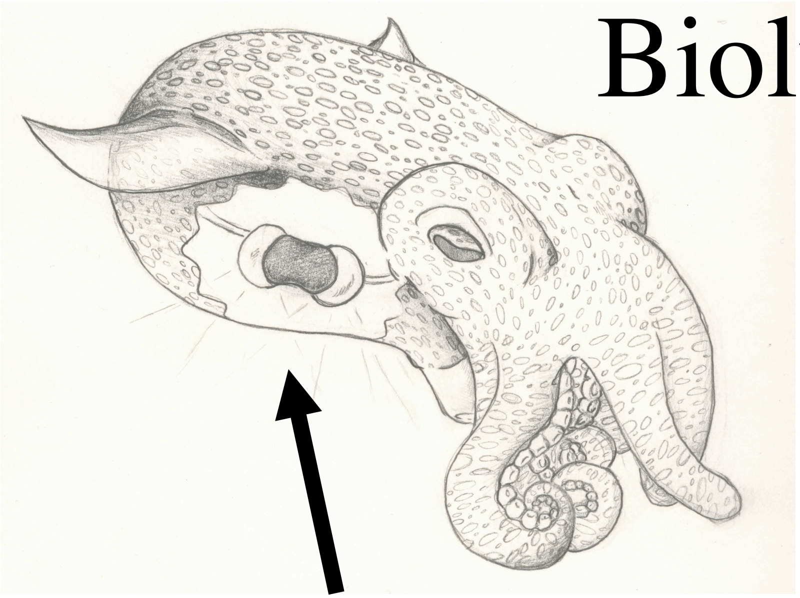


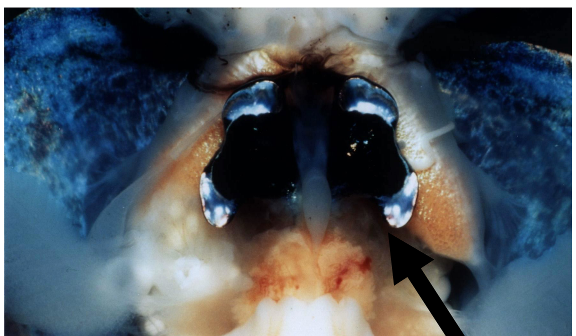
Figure 8.10 The luciferin of the firefly *Photinus*. The active part of all luciferins is the COOH terminal group, which in the excited state (indicated by *) forms a double-bonded CO group allied with a system of conjugated double bonds in the rest of the molecule. One photon is released.

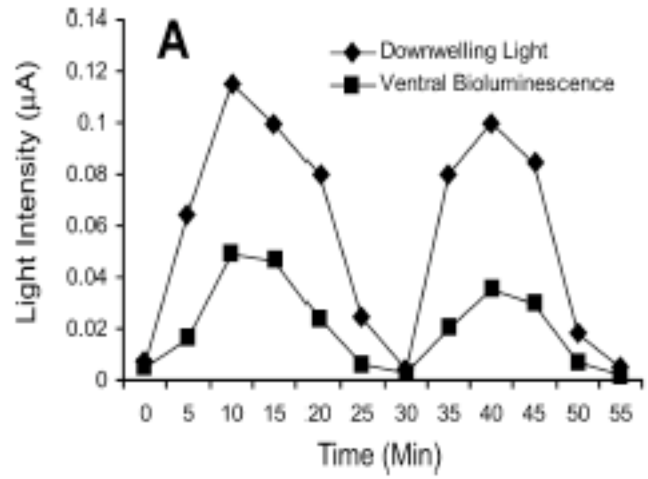
Bioluminescence is common among marine organisms, especially deep-sea fishes.

Bioluminescence in squid



- Created by symbiotic *Vibrio* bacteria
- Used for counter-illumination to downwelling moonlight

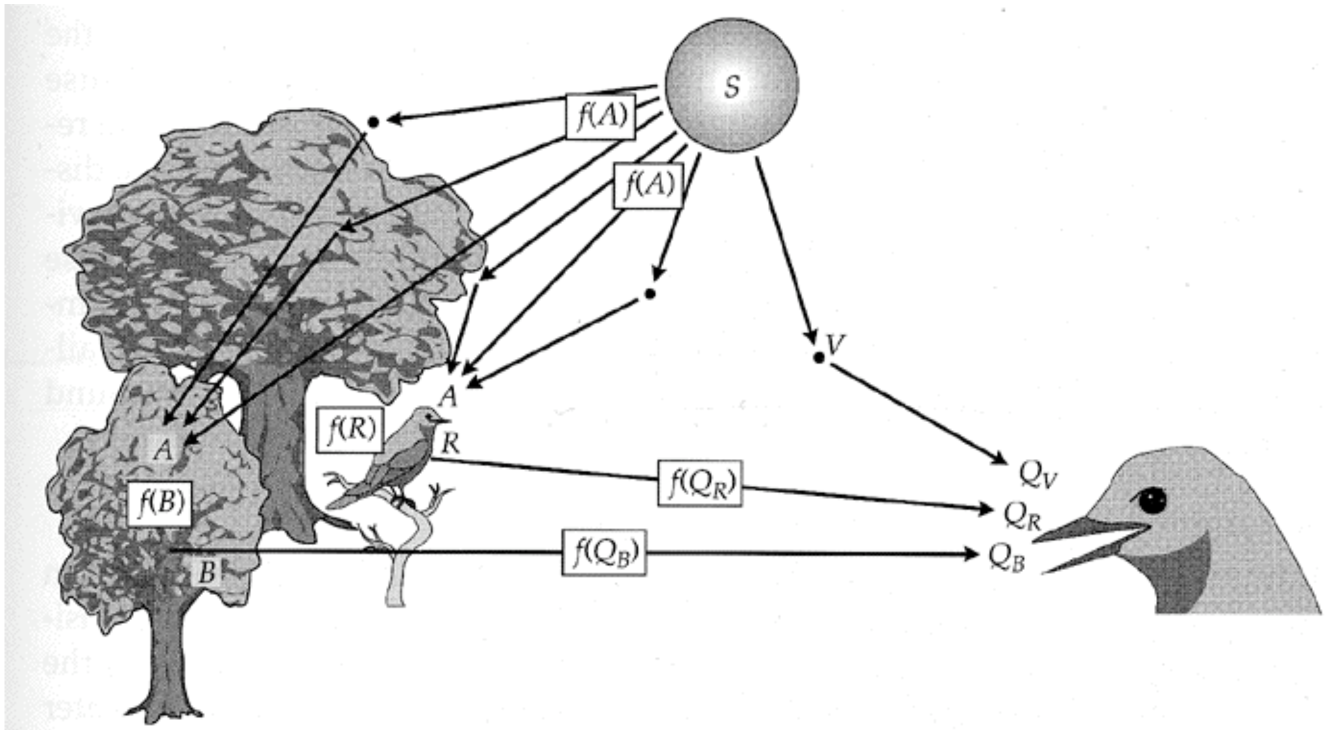




Jones & Nishiguchi, 2004, Marine Biology 144: 1151-1155

See http://www.lifesci.ucsb.edu/~biolum/organism/squid.html

Reception of light signals



- Receiver always receives veiling atmospheric light, reflected signal, and reflectance from background
- Must distinguish signal (Qr) from noise (Qv and Qb)

Habitat Transmission

- Color brightness of an object depends on wavelengths of available light
- Amount and spectral composition of available light can differ by habitat
- In terrestrial habitats, light spectra is influenced by angle of Sun, weather, vegetation
- Expect animals to utilize colors appropriate for habitats

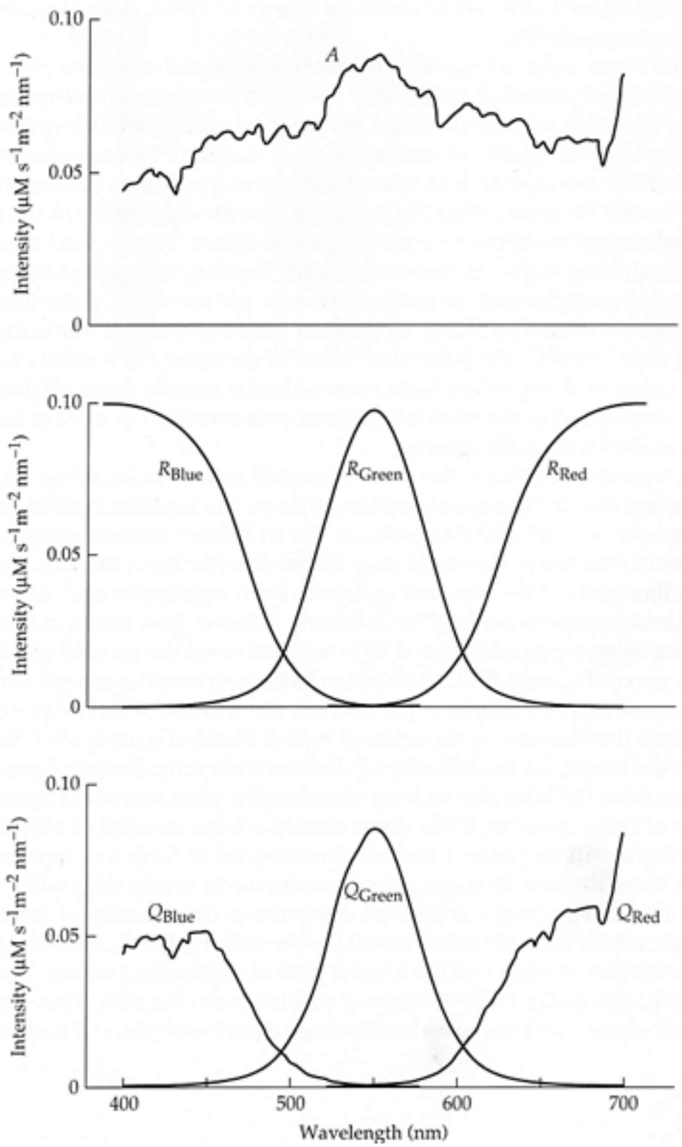
Light intensity variation

Table 8-5 Light Intensities in Various Environments

Situation	Intensity * (Photons cm^{-2} s^{-1} nm^{-1})
Full sunlight	10^{14}
Overcast daylight	10^{13}
Twilight	10^{11}
Moonlight	10^{8}
Clear moonless night (starlight + airglow)	10^{6}
Overcast moonless night	10^{5}
Full sunlight at 1000 m in clear ocean waters	10^{6}

* Spectral density near 500 nm (Lythgoe 1979, 4–6; Brines and Gould 1982).

Color filtering by habitat

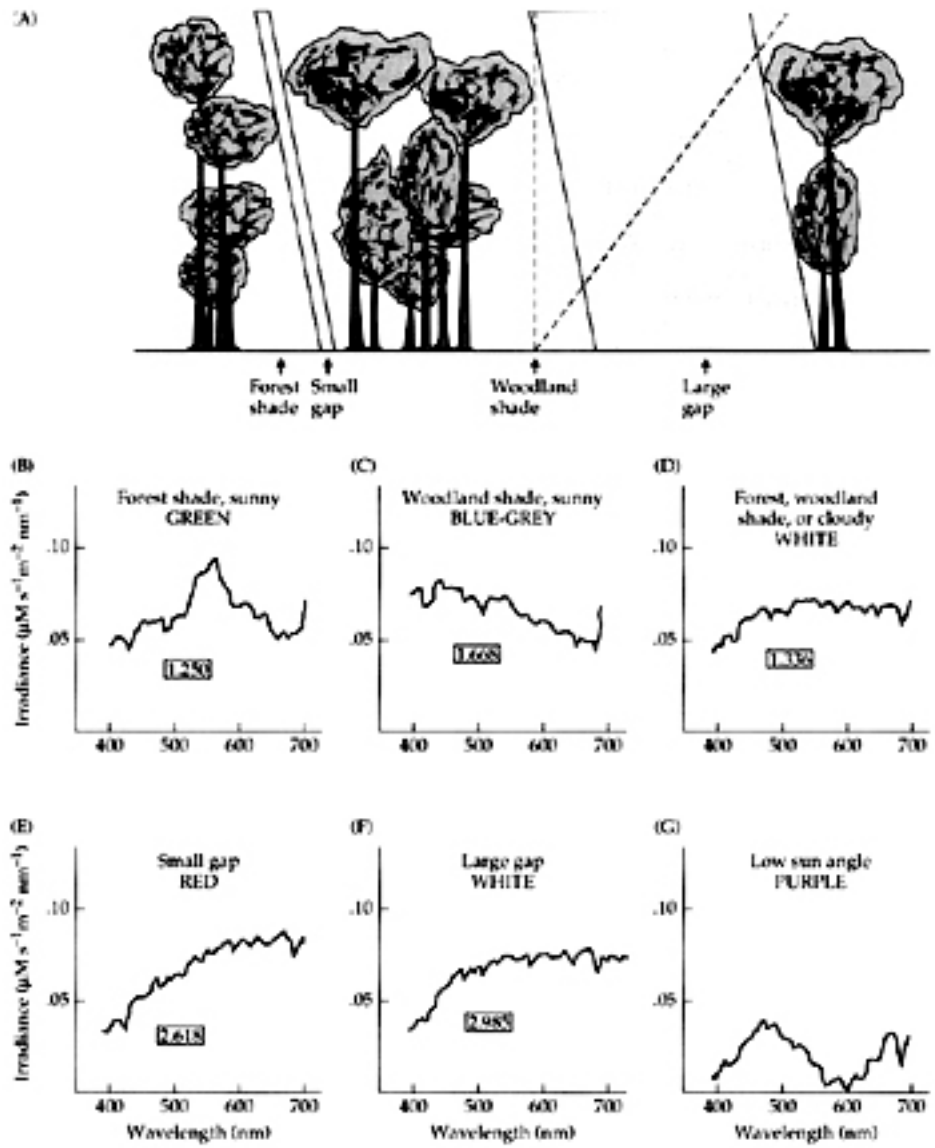


Spectra in forest

Colors in white light

Green colors are enhanced in forest

Light reflectance



Guppy Color Patterns

See Shockwave slide show at
http://www.pbs.org/wgbh/evolution/sex/guppy/index.html

Light attenuation

- Light attenuation follows inverse square law which is independent of wavelength
- Scattering and absorption, however, increase as wavelength decreases

Table 8.1 Light-beam attenuation lengths in different media.

	Wavelength (nm)					
Environment	**300**	**400**	**500**	**600**	**700**	**800**
Pure air	7.0 km	22 km	55 km	120 km	220 km	370 km
Clean air	3.8 km	5.0 km	6.0 km	6.7 km	7.4 km	7.9 km
Moderate fog	50 m	50 m	50 m	50 m	50 m	50 m
Pure water	?	23 m	28 m	5.4 m	2.0 m	0.49 m
Ocean	?	1–10 m	1–15 m	1–5 m	1–2 m	?

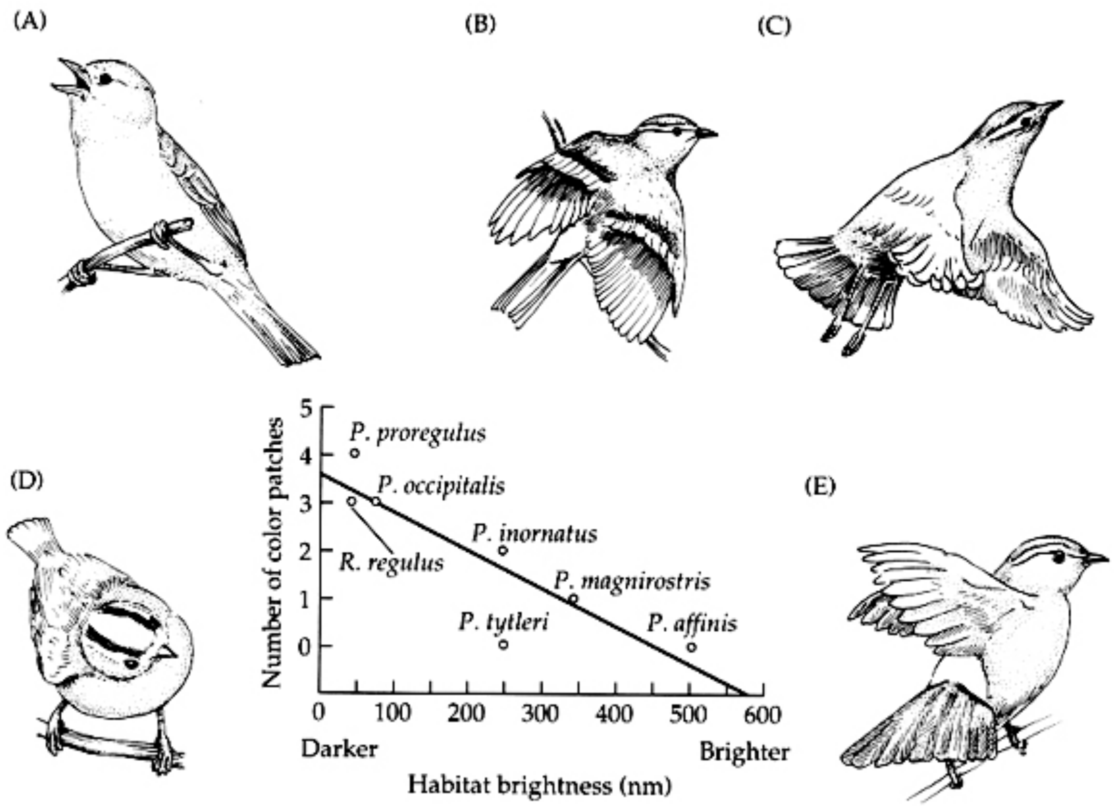
Source: Dusenbury 1992.

Signal detection

- Senders must produce a signal that contrasts from background using brightness, color, pattern or movement
- Can adopt countershading or reverse counter shading for crypsis or conspicuousness
- Visual systems often exaggerate contrast to detect objects in background

Signal contrast varies with habitat

Phylloscopus warblers



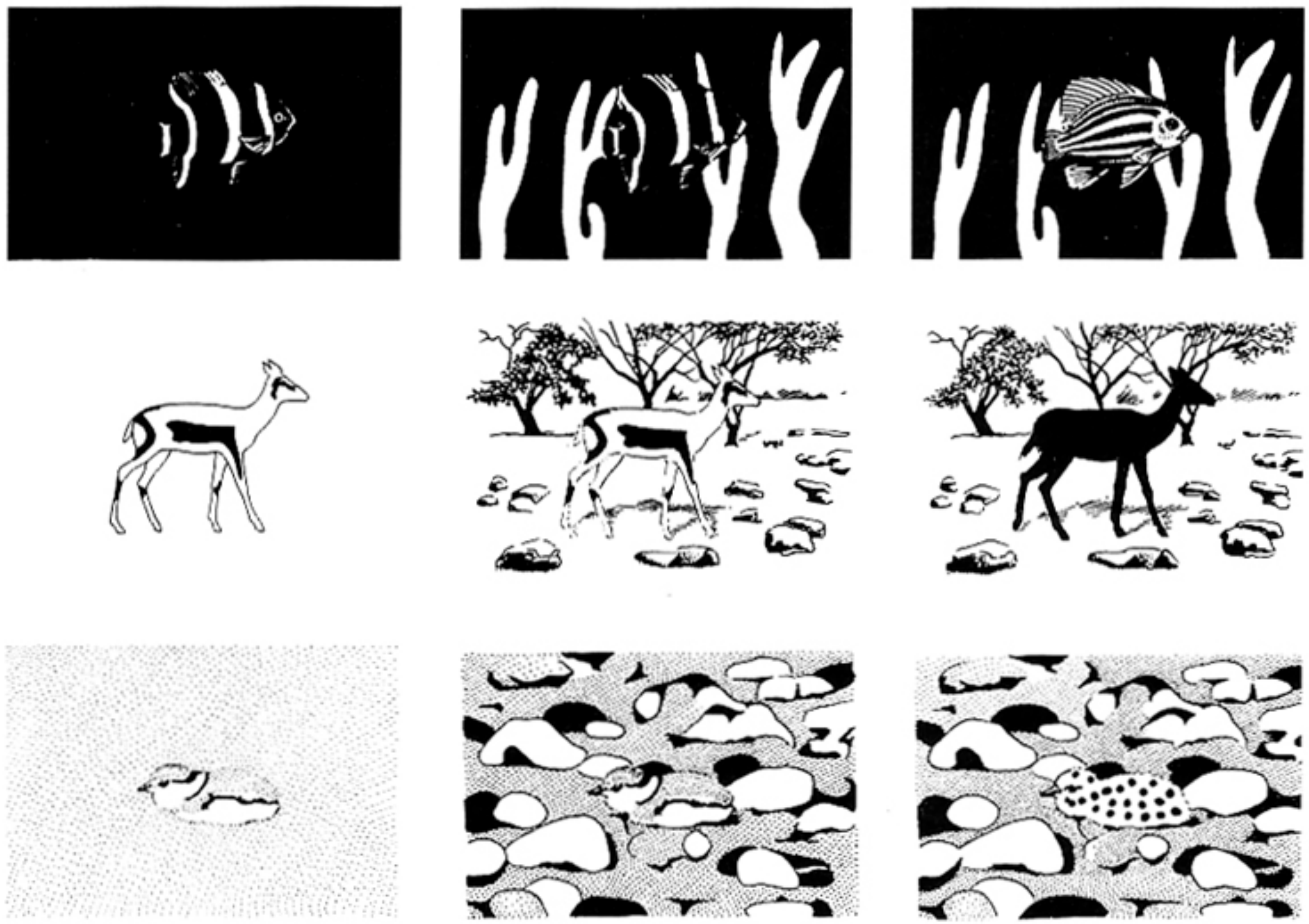
Optimal signal and background hues

Table 8.2 Optimal signal hue in different environments and backgrounds.

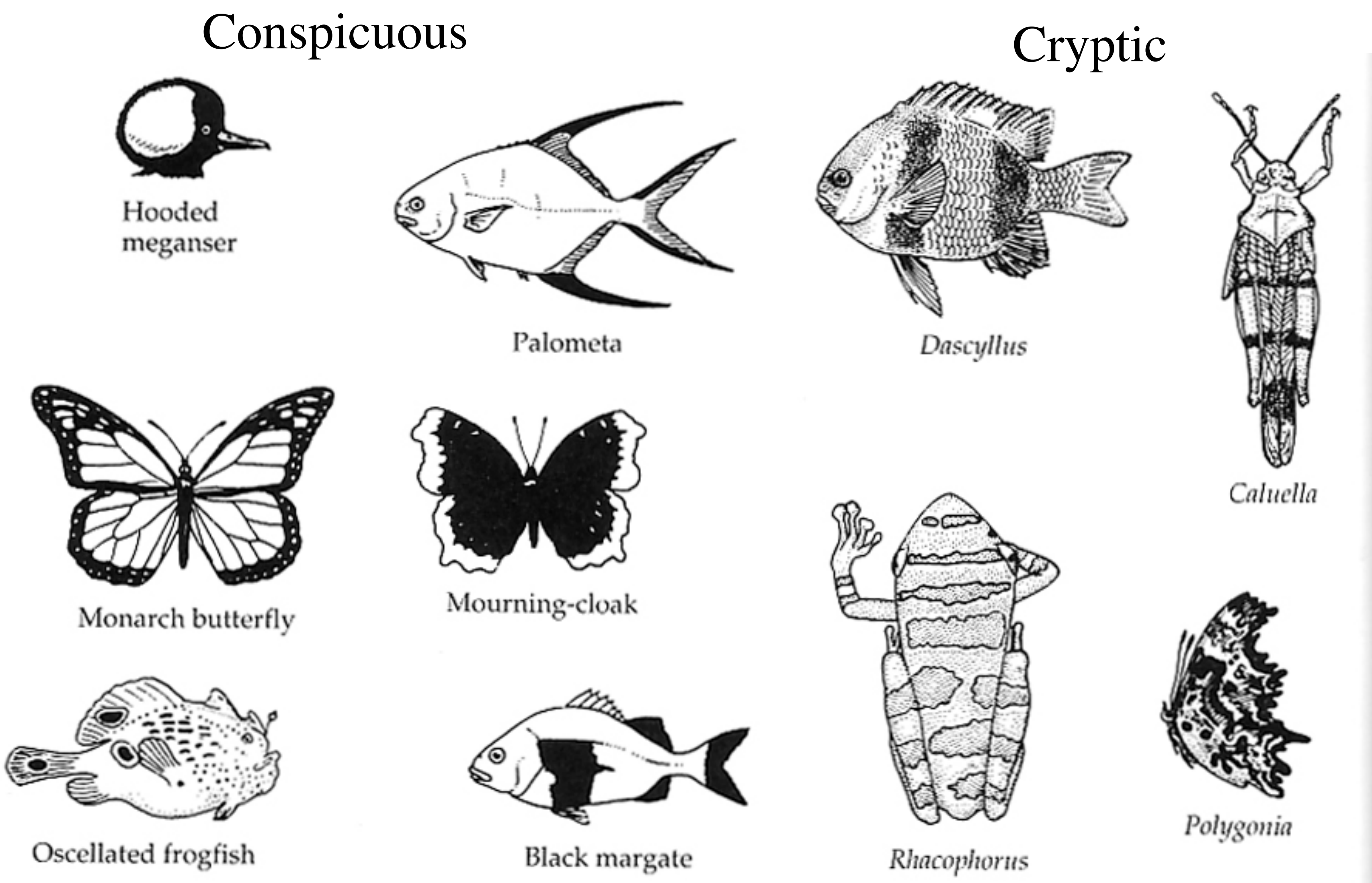
Habitat	Available light illumination level (hue)	Background hue	Optimal signal color
Night	Low (gray)	Black	White, biolumin
Open ocean, lake	Low to med. (blue)	Blue	Yellow
Marine reef	High (blue)	Blue	Red, yellow
Freshwater streams	Low to high (yellow-green)	Yellow-green	Blue, red
Tropical forest	Med. (green)	Green	Red
Temperate forest	Med. to high (green)	Yellow-green	Purple
Broadleaf litter	Med. (green)	Yellow	Blue
Forest tree trunk	Med. (green)	Orange	Blue-green
Grass, bush, marsh	High (white)	Yellow-green	Blue
Dried grass, old field	High (white)	Yellow	Blue
Sand dune	High (white)	Orange	Blue-green
Sky	High (white)	Blue	Black
Water surface	High (white)	Blue	Black or white
Low sun angle	Low, (purple)	Dark	White, yellow

Source: After Hailman 1979 and Lythgoe 1979.

Pattern contrast



Shape enhancement



Counter and reverse shading