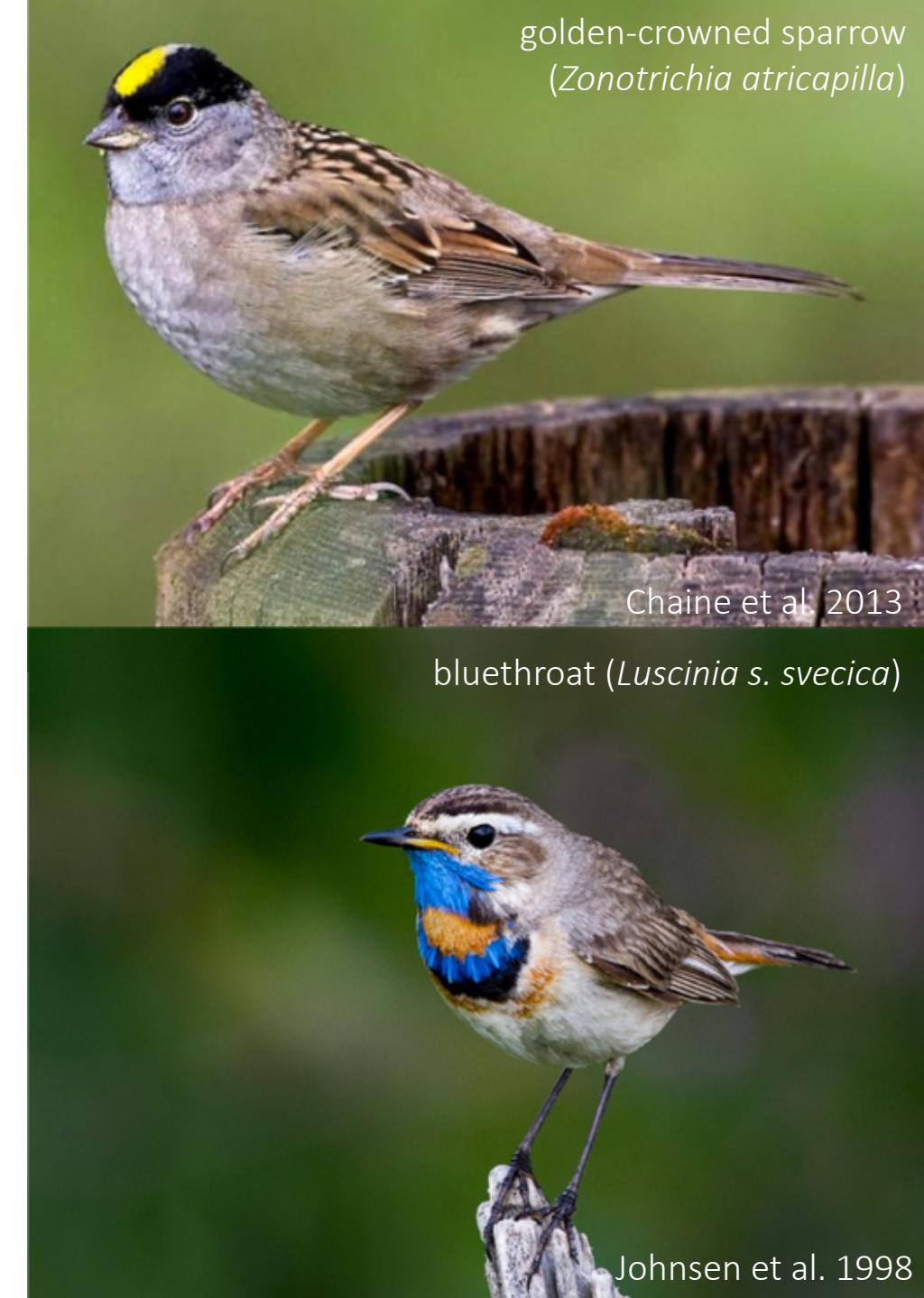


Achromatic plumage is  
morphologically distinct between  
sexually monochromatic  
chickadees

Katherine Feldmann



Plumage regulates  
reproductive interactions  
within species...



...and is thought to regulate reproductive interactions between species.



chestnut-bellied monarch  
(*Monarcha c. castaneiventris*)



white-capped monarch  
(*Monarcha c. richardsii*)

Previous studies suggest  
plumage plays a role in  
driving hybridization...

red-backed fairy wren  
(*Malurus melanocephalus*)



Baldassarre et al. 2013

golden-collared manakin  
(*Manacus vitellinus*)



Stein and Uy 2006

...these studies have focused on species with apparent sexual dichromatism.



# Achromatic Plumage

# Achromatic Plumage



tree swallow  
(*Tachycineta bicolor*)



Taff et al. 2019

pied flycatcher  
(*Ficedula hypoleuca*)



Cantarero et al. 2017

upland goose  
(*Chloephaga picta leucoptera*)



Gladbach et al. 2011

black-capped chickadee  
(*Poecile atricapillus*)



Mennill et al. 2003

Previous research has examined plumage color from a [human perspective](#)...

dichromatic



monochromatic



Unlike humans, birds perceive **ultraviolet light**

Trichromat (human)



Tetrachromat (bird)



Black-capped chickadees are sexually dichromatic  
from an avian perspective.



Although recent studies have begun to analyze plumage from an **avian perspective** and address the role of achromatic plumage within species...

Although recent studies have begun to analyze  
plumage from an avian perspective and address  
the role of achromatic plumage within species...

Although recent studies have begun to analyze plumage from an **avian perspective** and address the role of **achromatic plumage** within species...

...few studies have determined the role of achromatic plumage between “sexually monochromatic” species from an avian perspective.

mountain chickadee  
(*Poecile gambeli*)



black-capped chickadee  
(*Poecile atricapillus*)



Achromatic plumage

mountain chickadee  
(*Poecile gambeli*)



black-capped chickadee  
(*Poecile atricapillus*)



Achromatic plumage

Sexually monochromatic from a  
human perspective



mountain chickadee  
(*Poecile gambeli*)



black-capped chickadee  
(*Poecile atricapillus*)

Achromatic plumage

Sexually monochromatic from a  
human perspective

Occasionally hybridize in regions of  
range overlap



mountain chickadee  
(*Poecile gambeli*)



black-capped chickadee  
(*Poecile atricapillus*)

# Research Question

How does plumage vary **between** black-capped and mountain chickadees as well as across **sexes** of each species from an **avian perspective**?

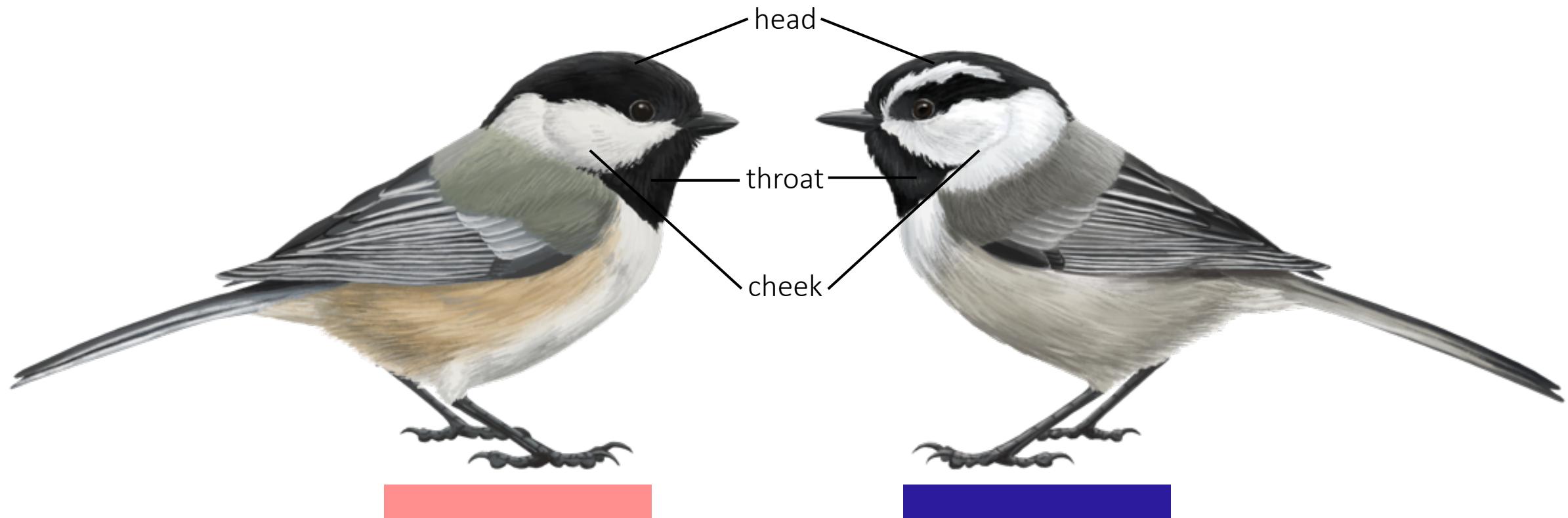
# Question 1

How does patch size vary between and within black-capped and mountain chickadees?

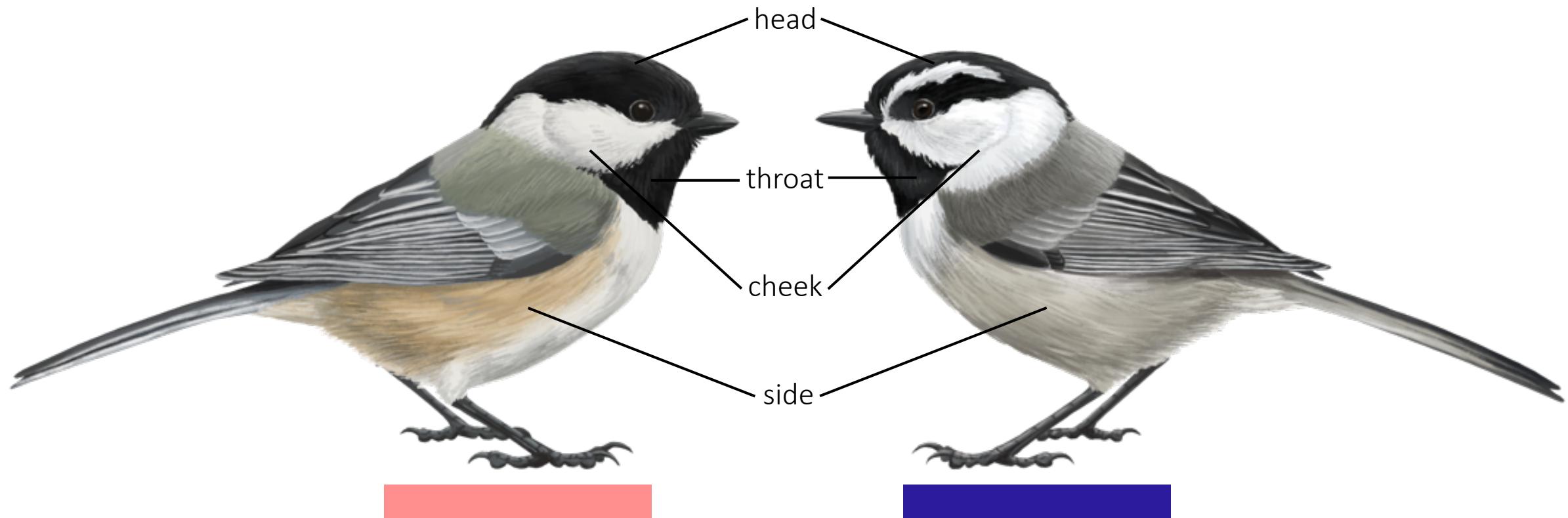
## Question 2

How does feather color vary between and within  
black-capped and mountain chickadees?

Plumage patches measured for feather color and [patch size](#).



Plumage patches measured for feather color and patch size.



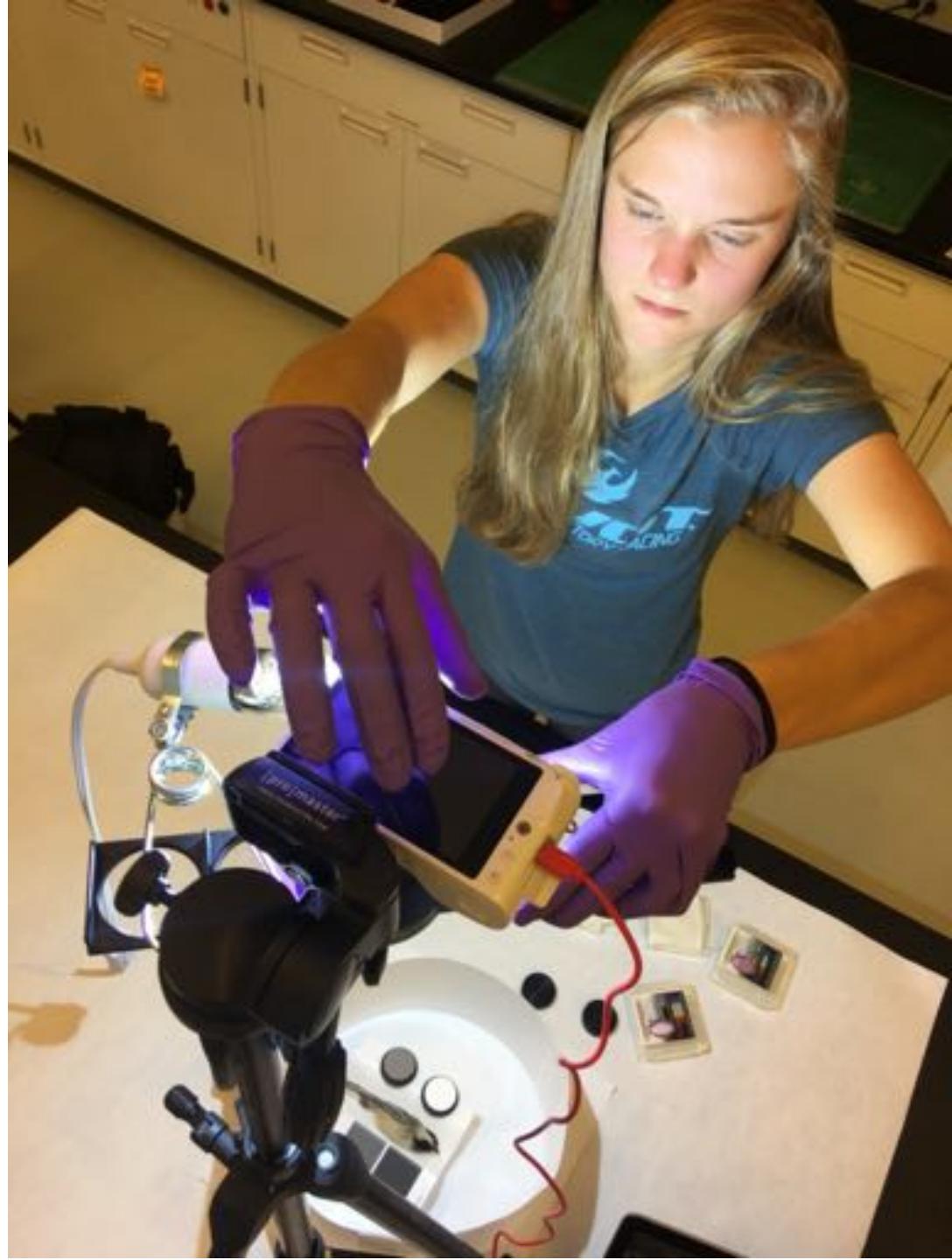
## White eyebrow stripe in mountain chickadees



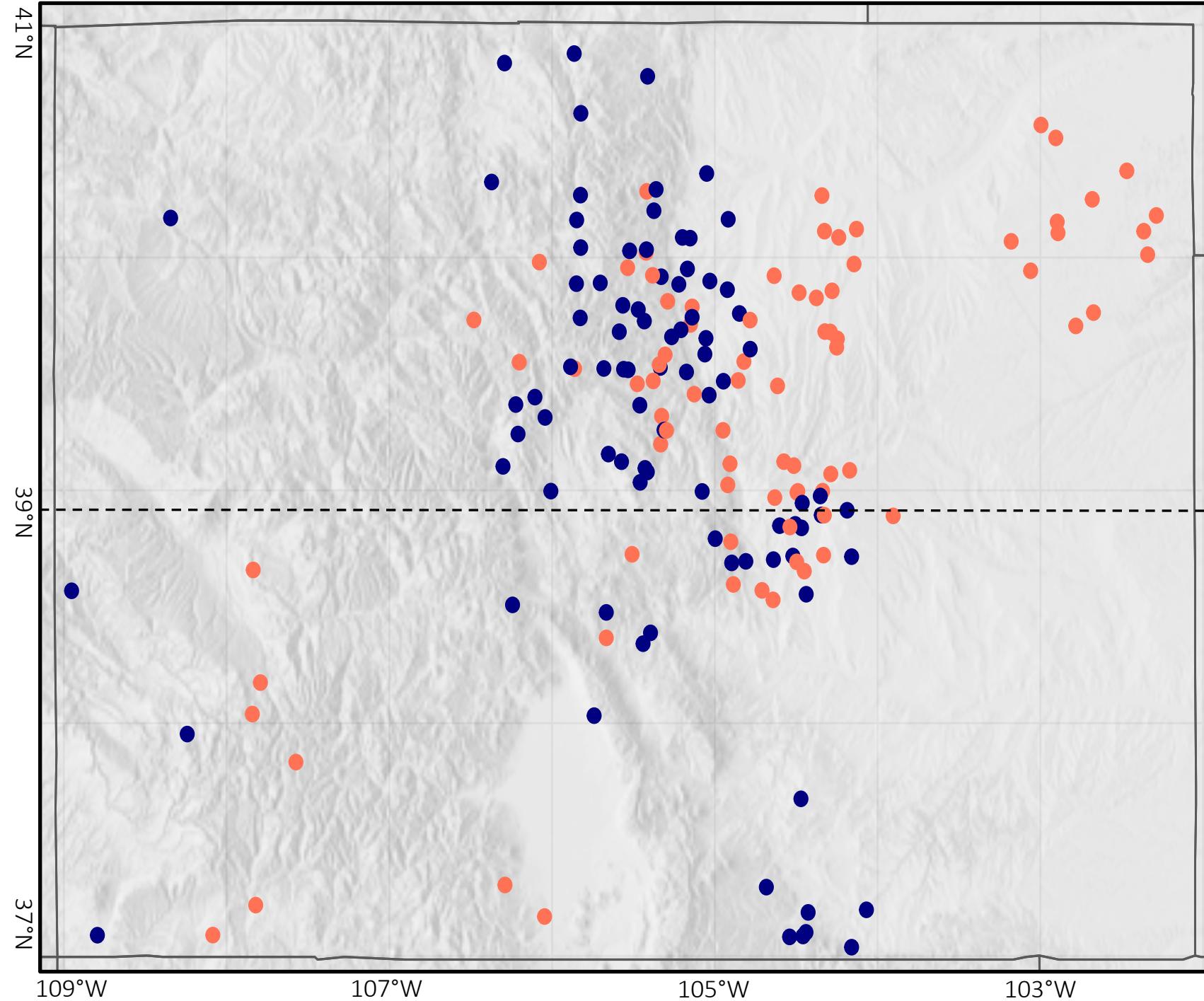
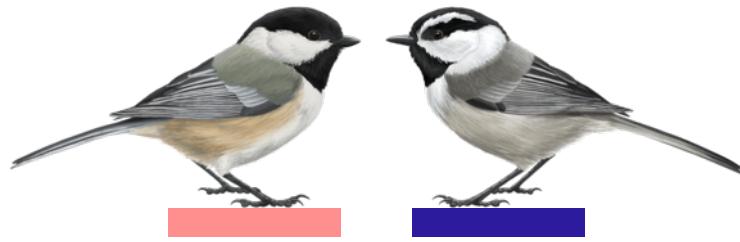
# Patch Size



# Digital Photography



Museum specimens  
collected from  
throughout Colorado



Camera sensitive to [visible](#) and [ultraviolet](#) wavelengths.



Camera sensitive to visible and ultraviolet wavelengths.

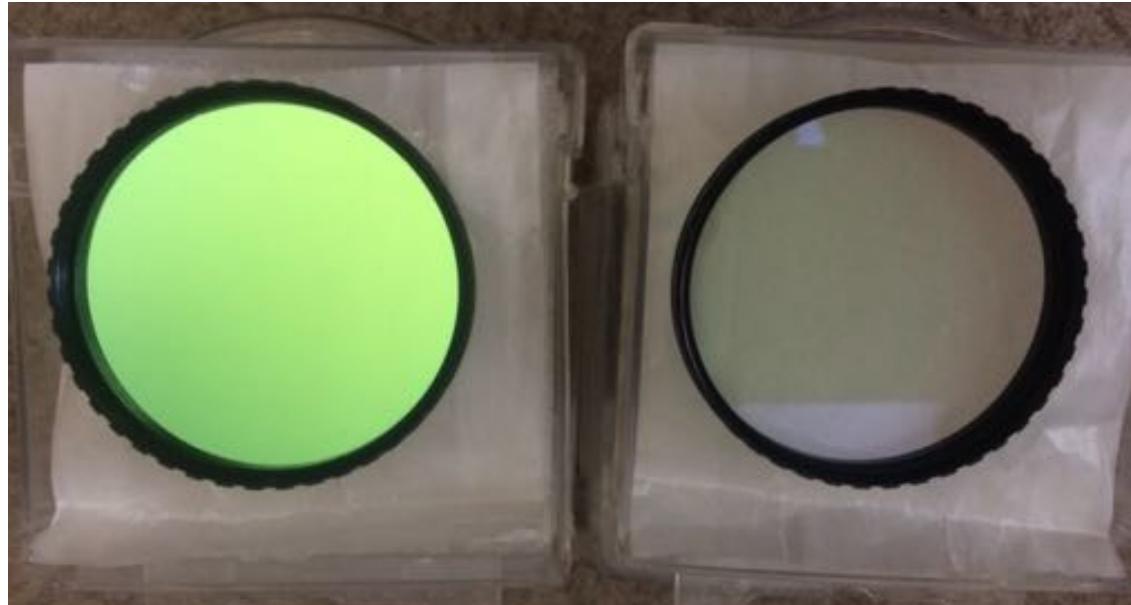
Lightbulb that emulates natural light and emits [visible](#) and [ultraviolet](#) wavelengths.



Camera sensitive to visible and ultraviolet wavelengths.

Lightbulb that emulates natural light and emits visible and ultraviolet wavelengths.

Filters that allow either [visible](#) or [ultraviolet](#) wavelengths to pass through the camera lens.



Camera sensitive to visible and ultraviolet wavelengths.

Lightbulb that emulates natural light and emits visible and ultraviolet wavelengths.

Filters that allow either visible or ultraviolet wavelengths to pass through the camera lens.

Standards that reflect a specified amount of light across the **visible** and **ultraviolet** spectrum.



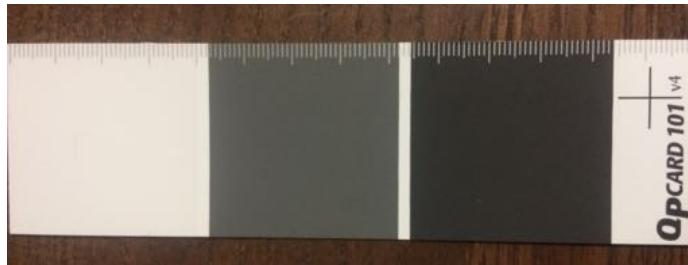
Camera sensitive to visible and ultraviolet wavelengths.

Lightbulb that emulates natural light and emits visible and ultraviolet wavelengths.

Filters that allow either visible or ultraviolet wavelengths to pass through the camera lens.

Standards that reflect a specified amount of light across the visible and ultraviolet spectrum.

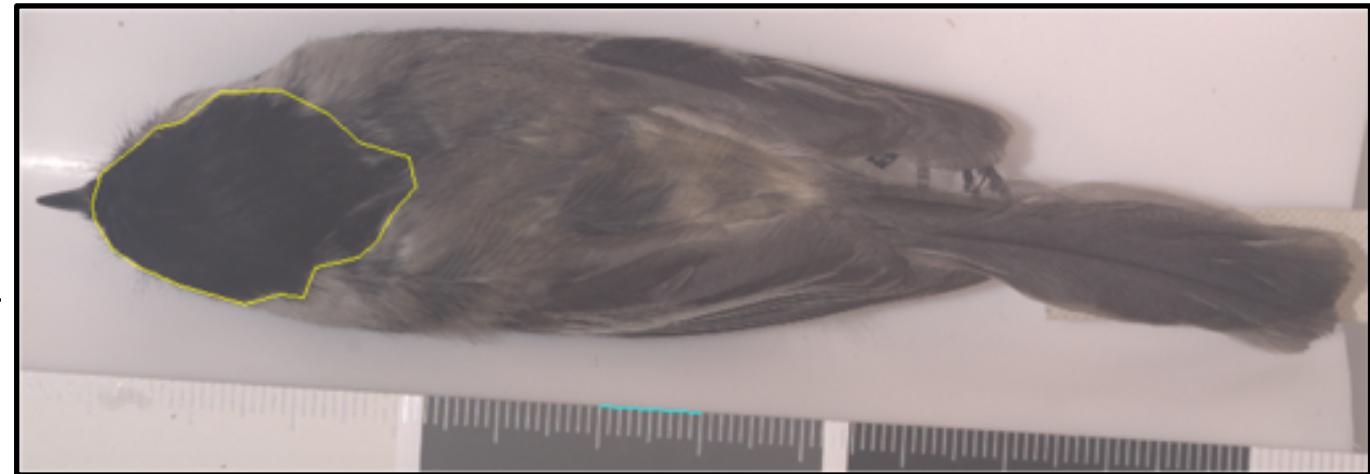
Scale bar that allows quantification of [area](#) from a photograph.



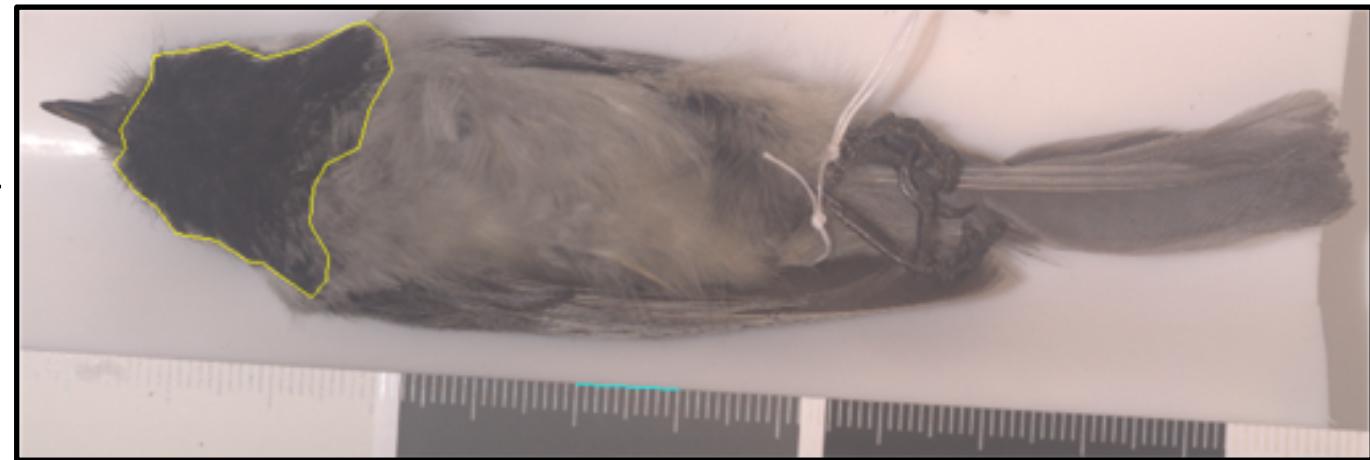
# Area analysis of museum specimens



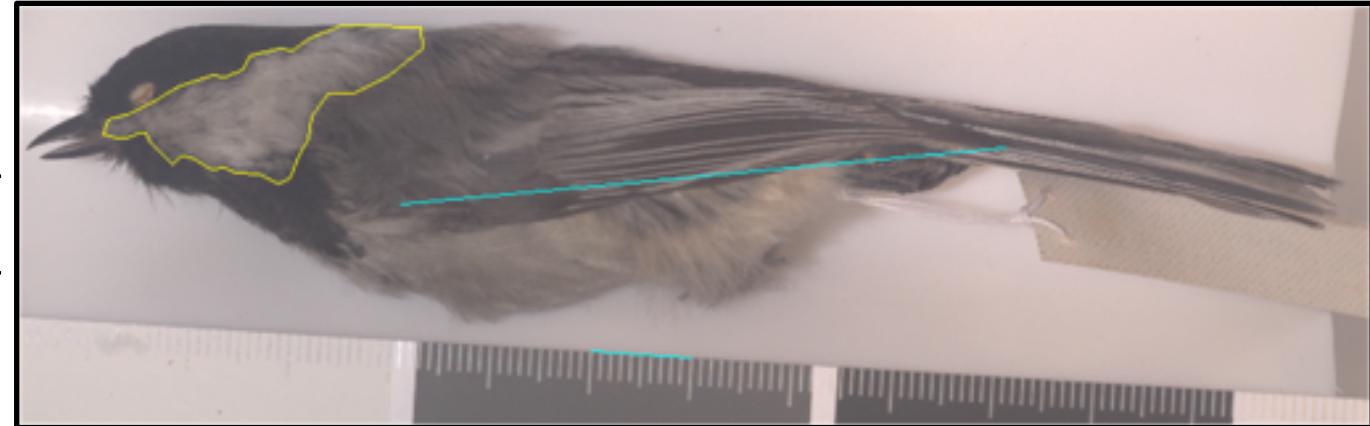
Head



Throat



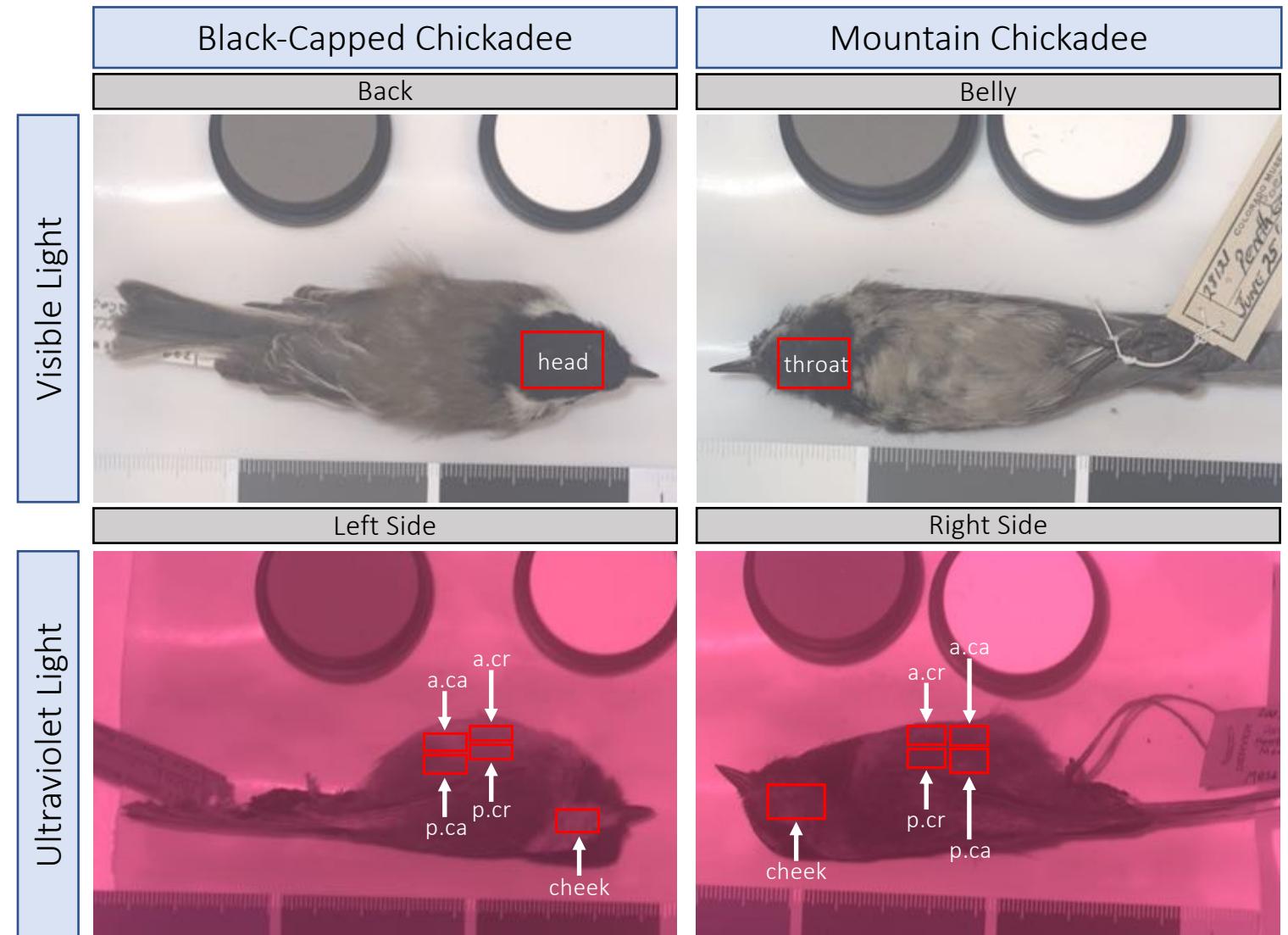
Cheek



# Plumage Color



# Color analysis of museum specimens

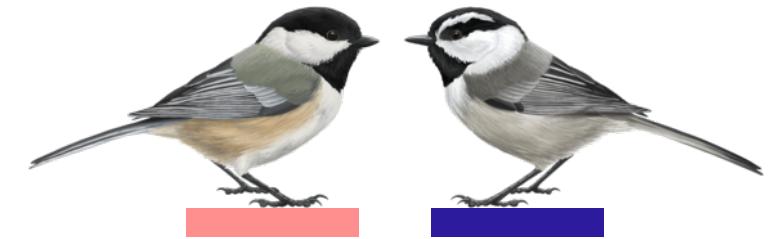
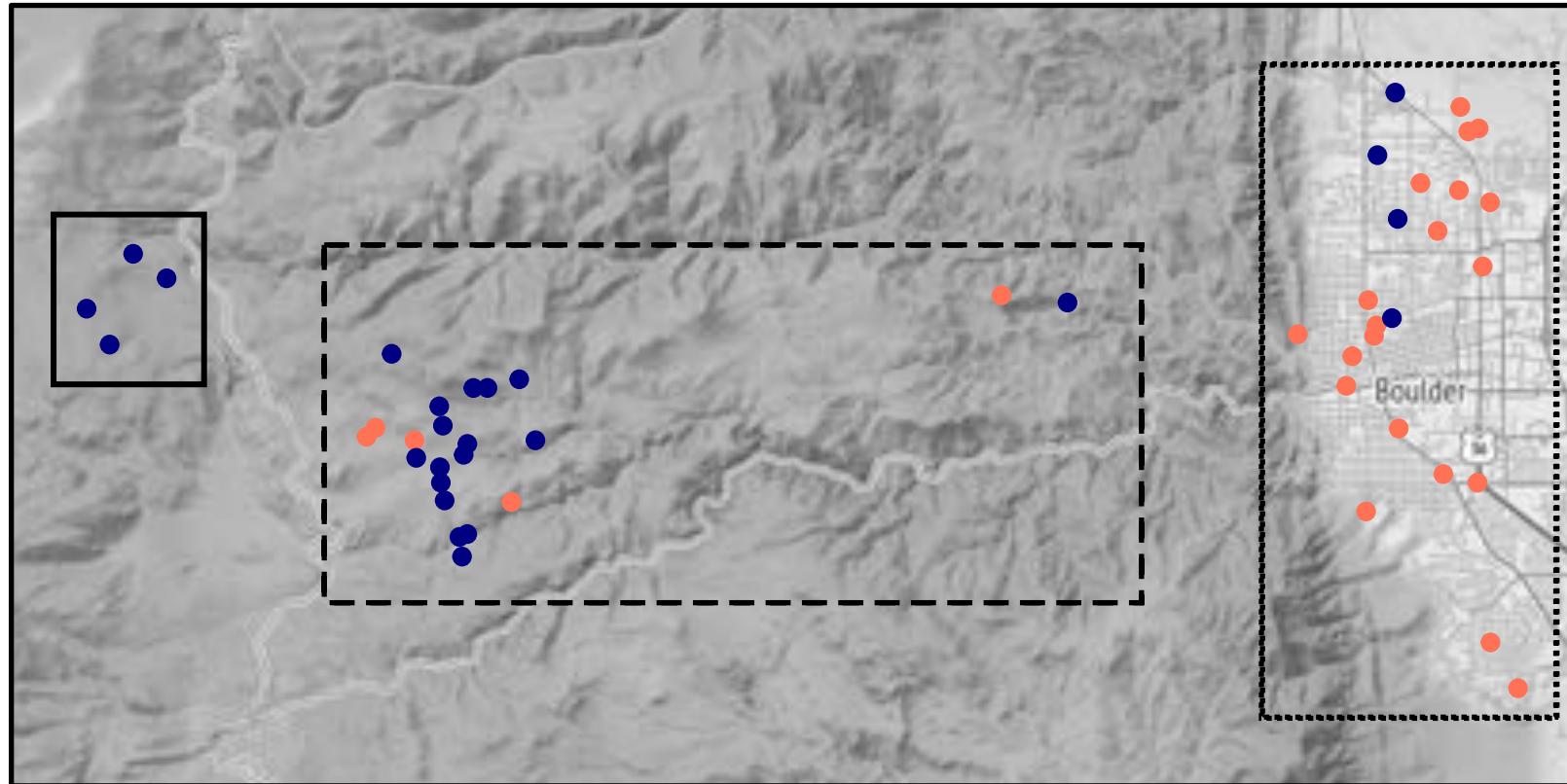


Troscianko et al. 2015

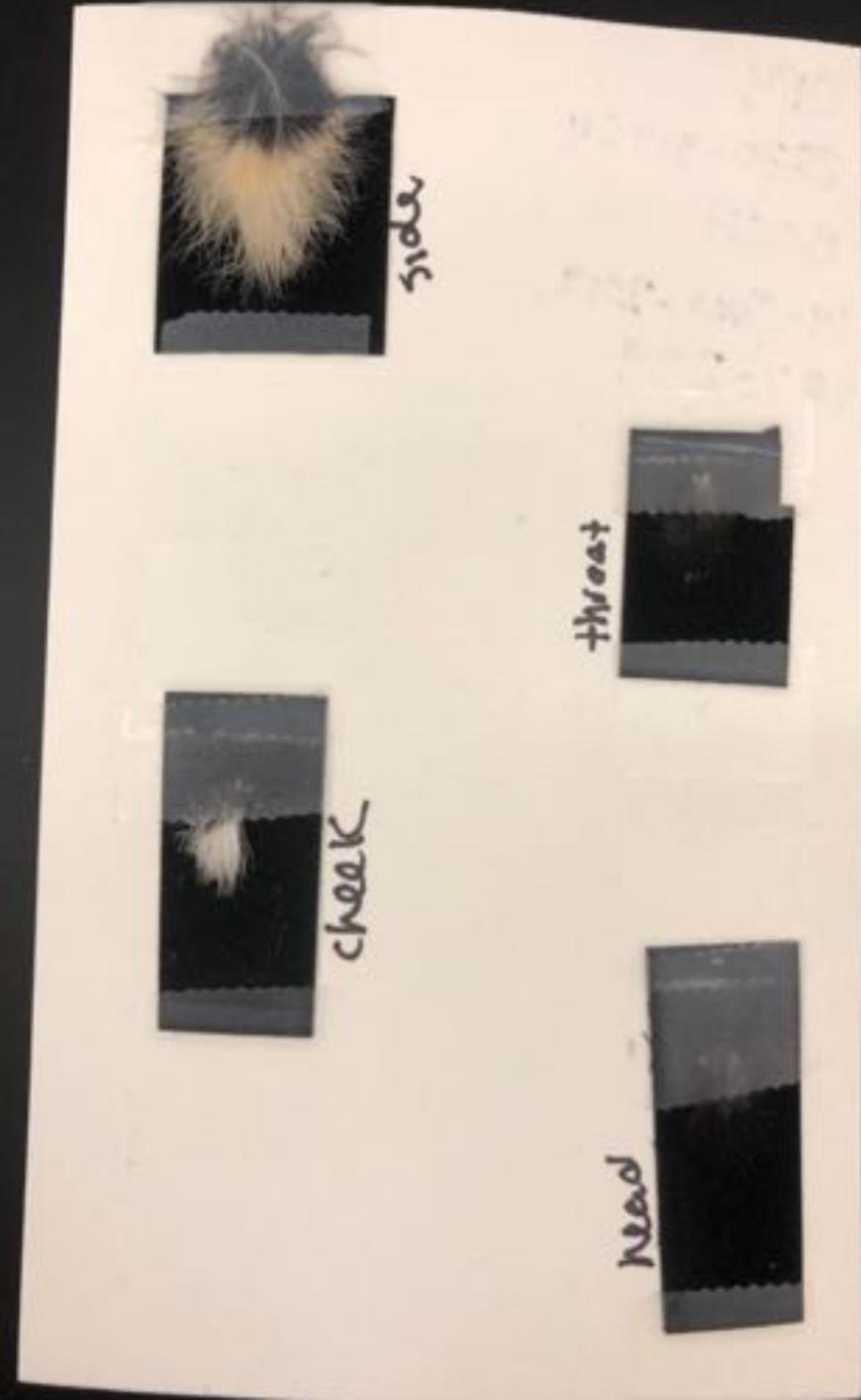
# Spectrophotometer



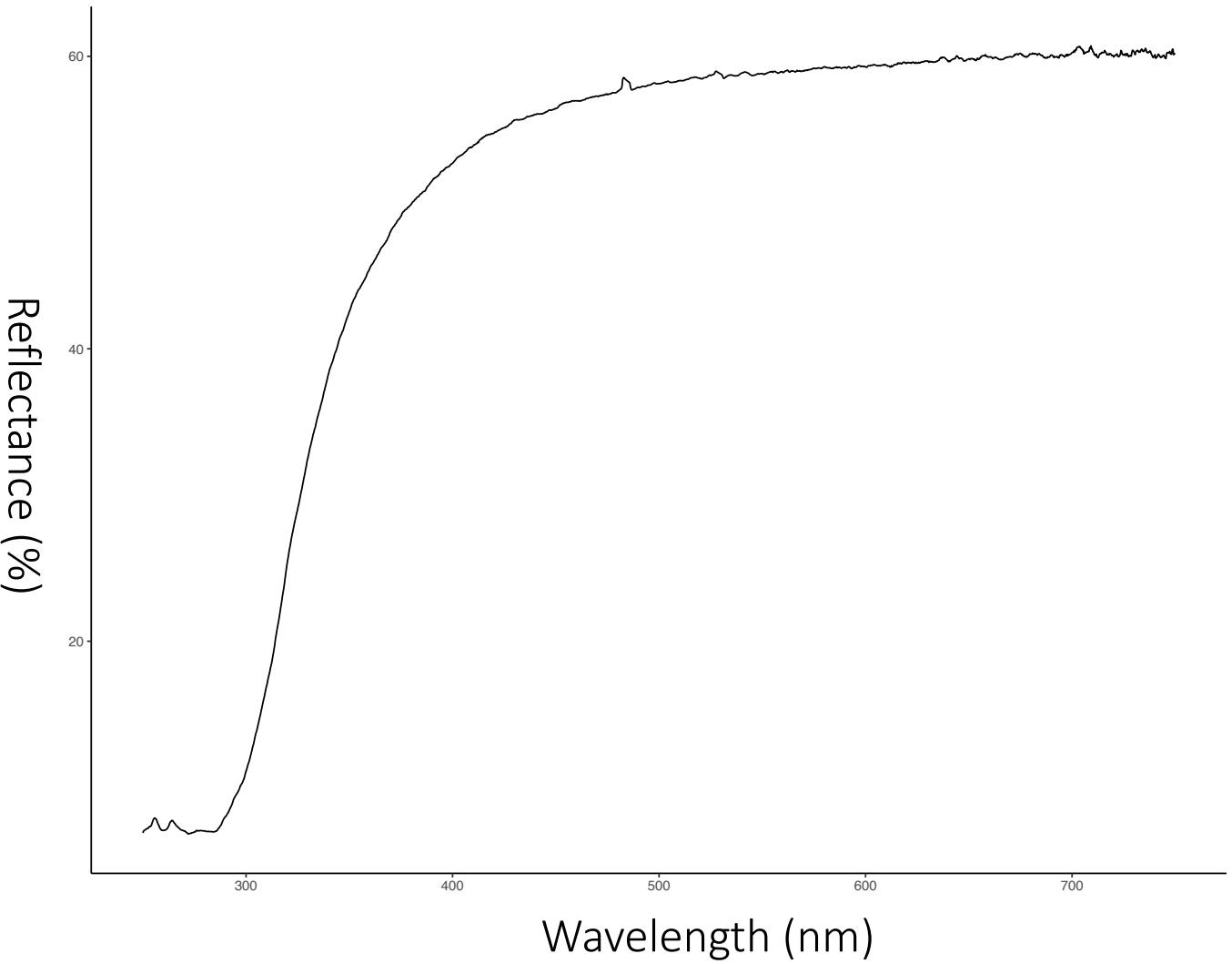
# Feathers from live birds collected from in and around Boulder, Colorado



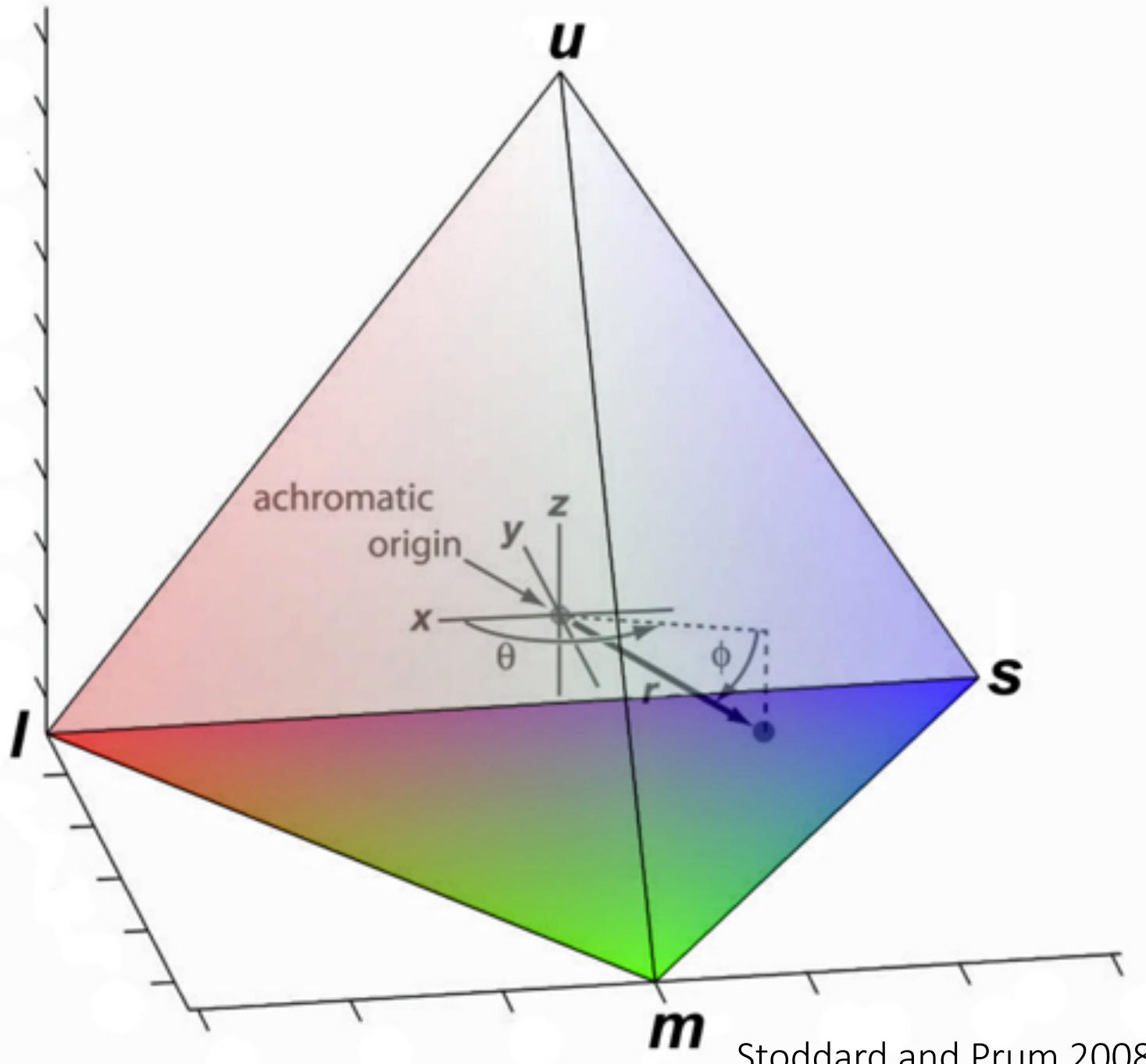
**Stacked feathers** for each  
individual for all patches.



Measured reflectance spectra (300 – 700 nm) for each patch using a spectrophotometer.



# TetraColorSpace



Stoddard and Prum 2008

For every patch, for each individual...

For every patch, for each individual...

Digital Photography 

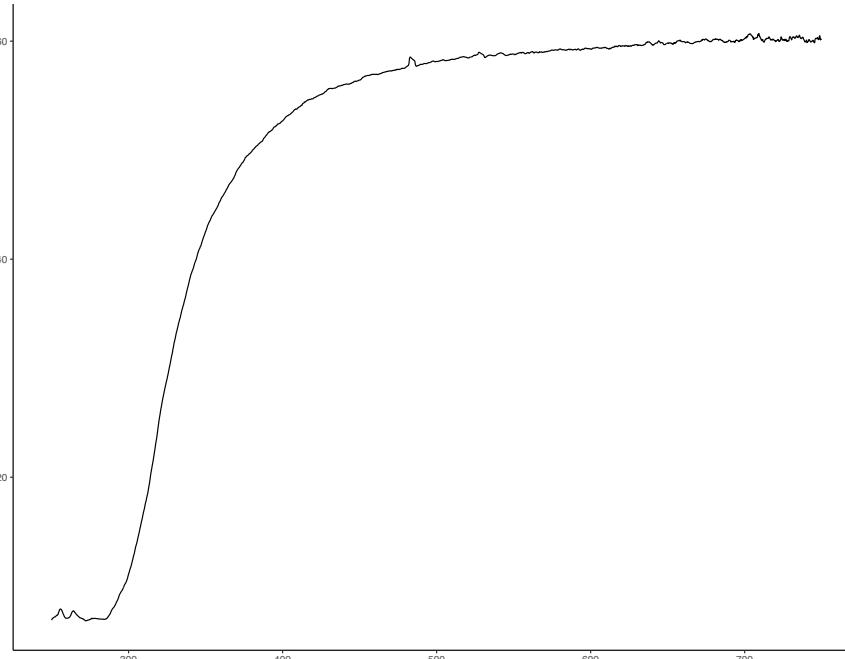
longwave	mediumwave	shortwave	ultraviolet
33.4	54.6	90.1	23.7

# For every patch, for each individual...

Digital Photography 

longwave	mediumwave	shortwave	ultraviolet
33.4	54.6	90.1	23.7

Spectrophotometry 

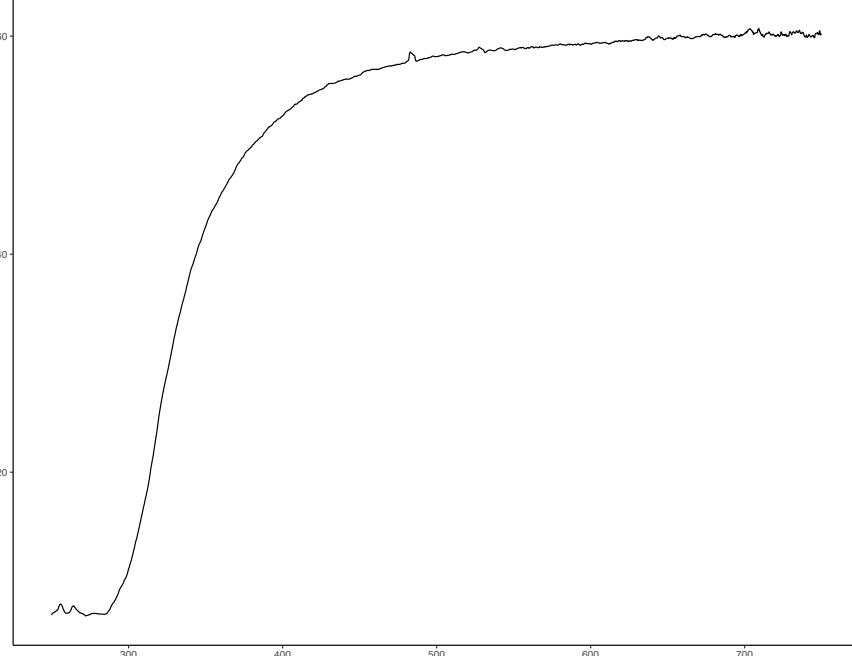


# For every patch, for each individual...

Digital Photography 

longwave	mediumwave	shortwave	ultraviolet
33.4	54.6	90.1	23.7

Spectrophotometry 



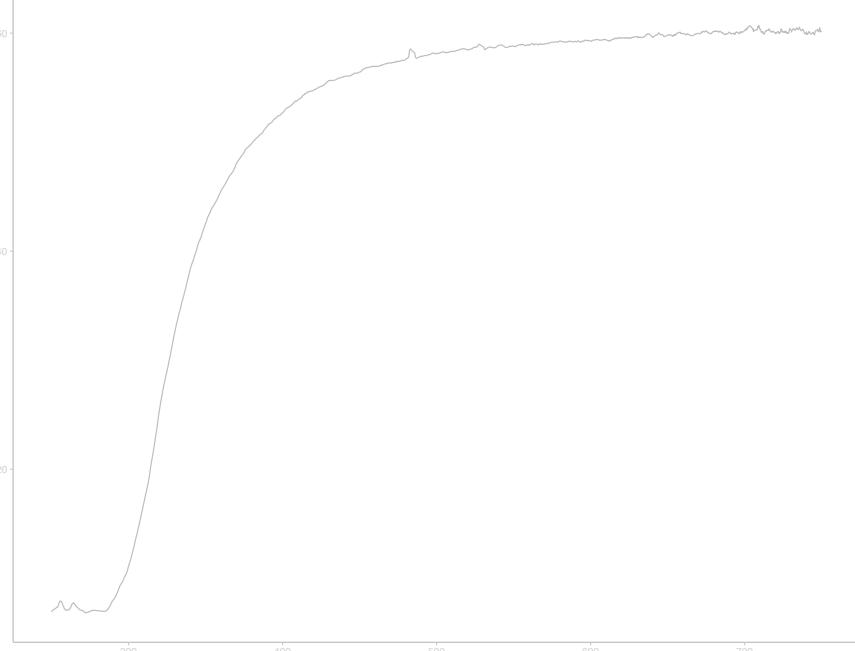
Hue ( $\Theta$  and  $\phi$ )  
Achieved Chroma  
Normalized Brilliance  
Wavelength at Maximum Reflectance  
Color Span  
Hue Disparity  
Average Chroma Volume

For every patch, for each individual...

Digital Photography 

longwave	mediumwave	shortwave	ultraviolet
33.4	54.6	90.1	23.7

Spectrophotometry 



Hue ( $\Theta$  and  $\phi$ )  
Achieved Chroma  
Normalized Brilliance  
Wavelength at Maximum Reflectance  
Color Span  
Hue Disparity  
Average Chroma Volume

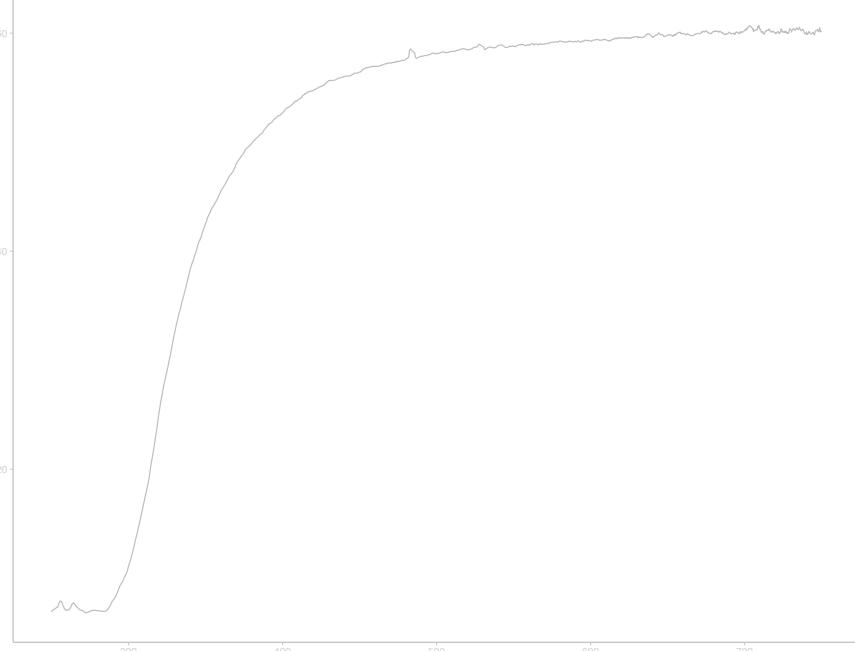


For every patch, for each individual...

Digital Photography 

longwave	mediumwave	shortwave	ultraviolet
33.4	54.6	90.1	23.7

Spectrophotometry 



Hue ( $\Theta$  and  $\phi$ )  
Achieved Chroma  
Normalized Brilliance  
Wavelength at Maximum Reflectance  
Color Span  
Hue Disparity  
Average Chroma Volume

# Statistical Analyses: Principal Component Analysis

Method	Patch	# Models
	Head	3
	Throat	3
	Cheek	3
	Side	3
	Contrast	3
	Head	✗
	Throat	✗
	Cheek	2
	Side	2
	Contrast	2

Principal components that account for 85% of the variation were used as **response variables**.

# Statistical Analyses: Linear Mixed Model



**PC** =  $\alpha + \beta_1(\text{Species})_1 + \beta_2(\text{Sex})_2 + \beta_3(\text{Julian Date})_3 + \beta_4(\text{Museum})_4 + (\text{fYear Collected}) + (\text{fQuadrant})$



**PC** =  $\alpha + \beta_1(\text{Species})_1 + \beta_2(\text{Sex})_2 + \beta_3(\text{Julian Date})_3 + (\text{fLocation}) + (\text{fBox Number}) + (\text{fNumber of Patch Feathers})$

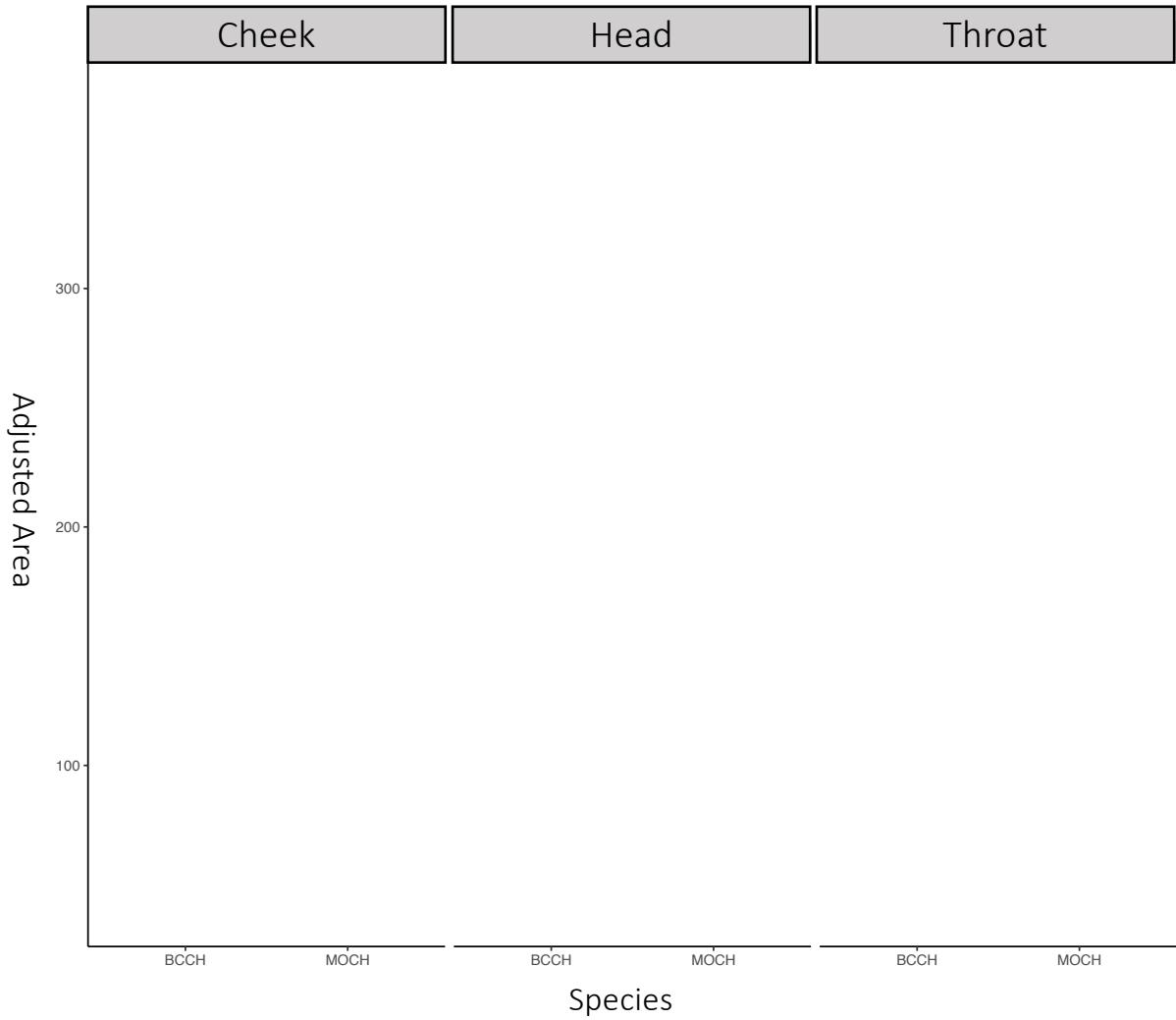
# Patch Size



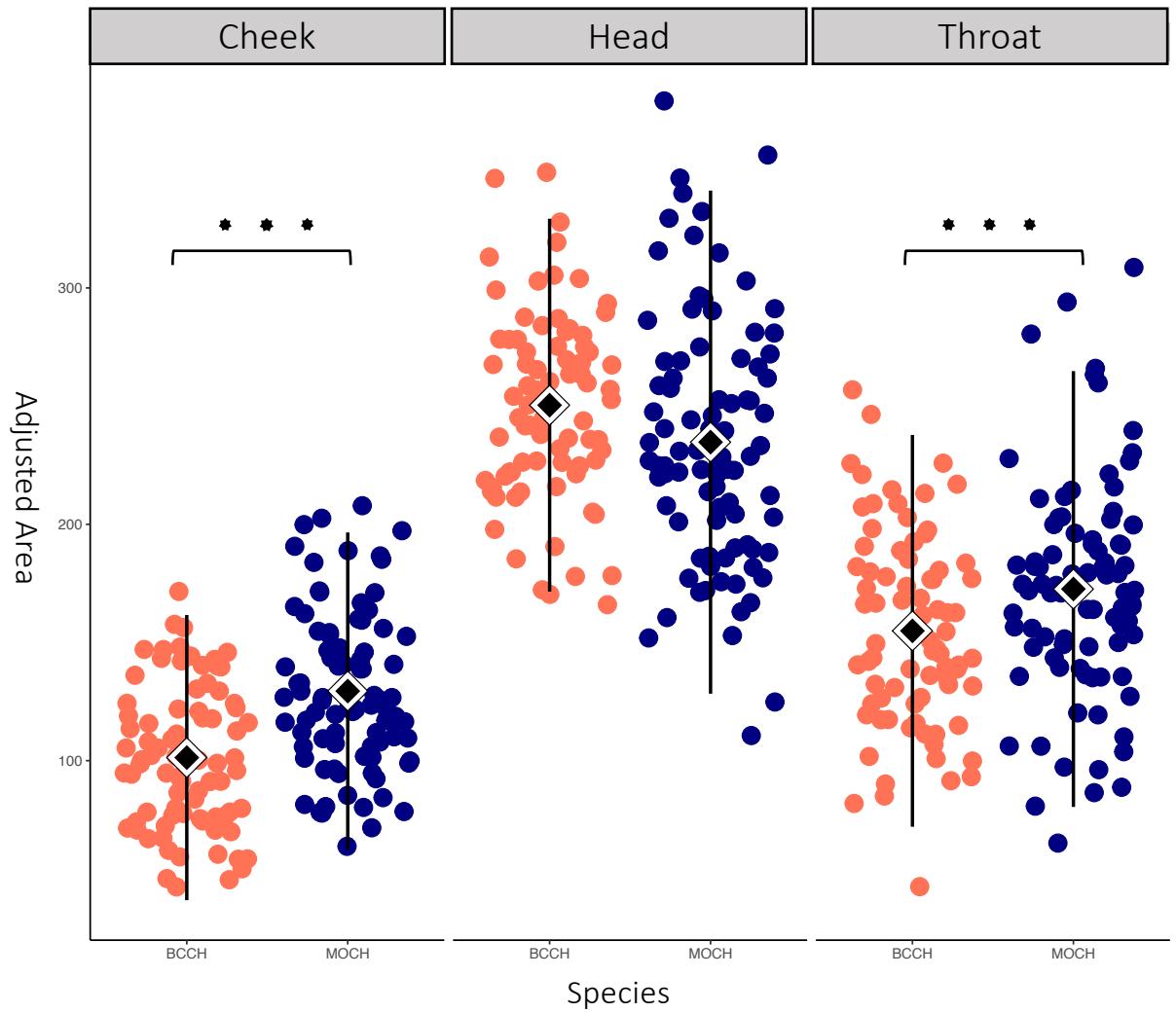
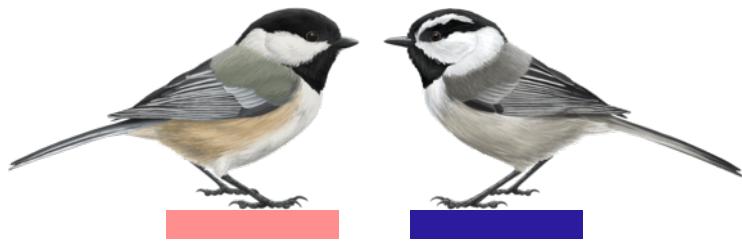
# Species



Mountain chickadees have  
*larger* plumage patches.



Mountain chickadees have  
**larger** plumage patches.



# Sex

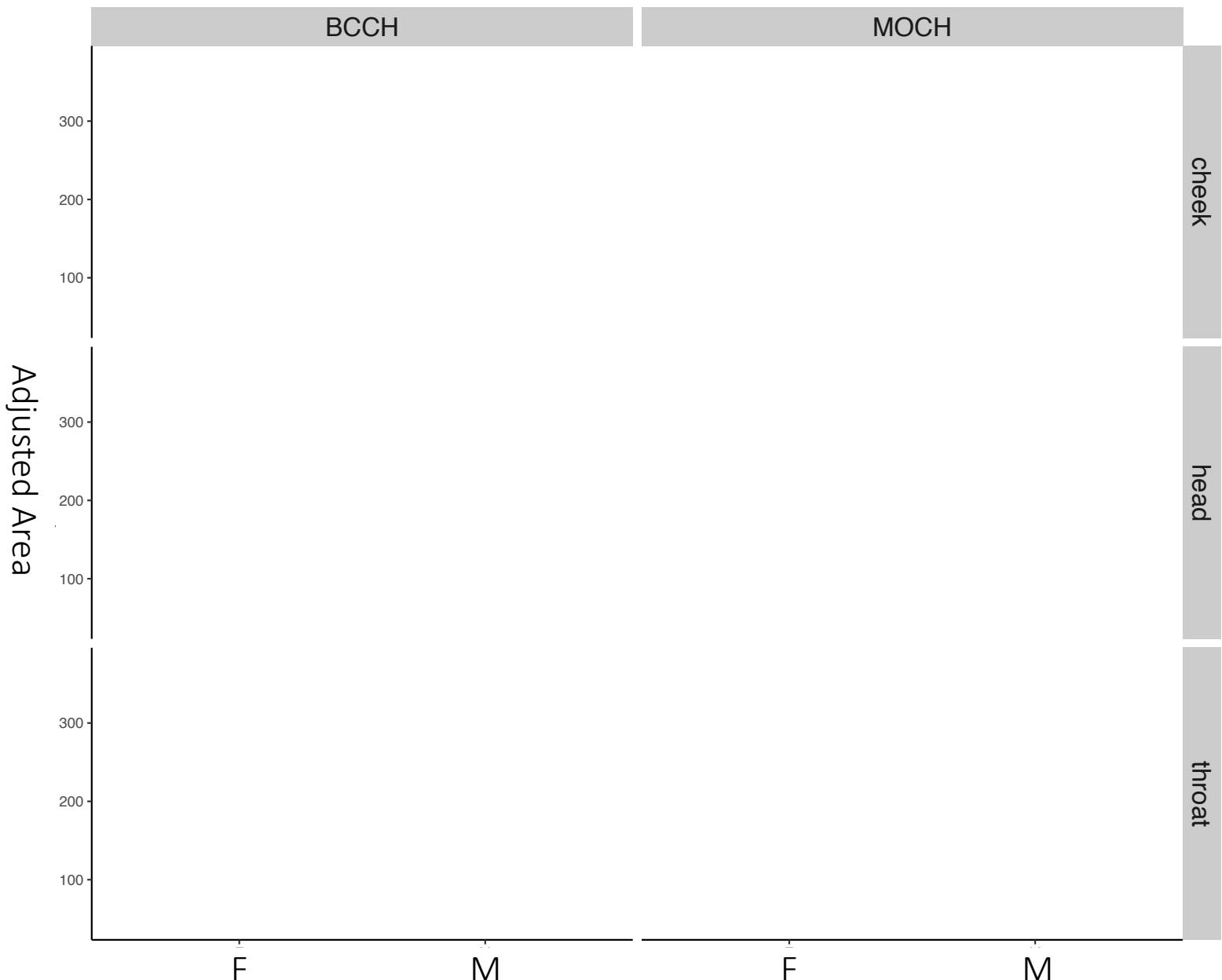


Males and females  
have the same patch  
area in either species.

♀



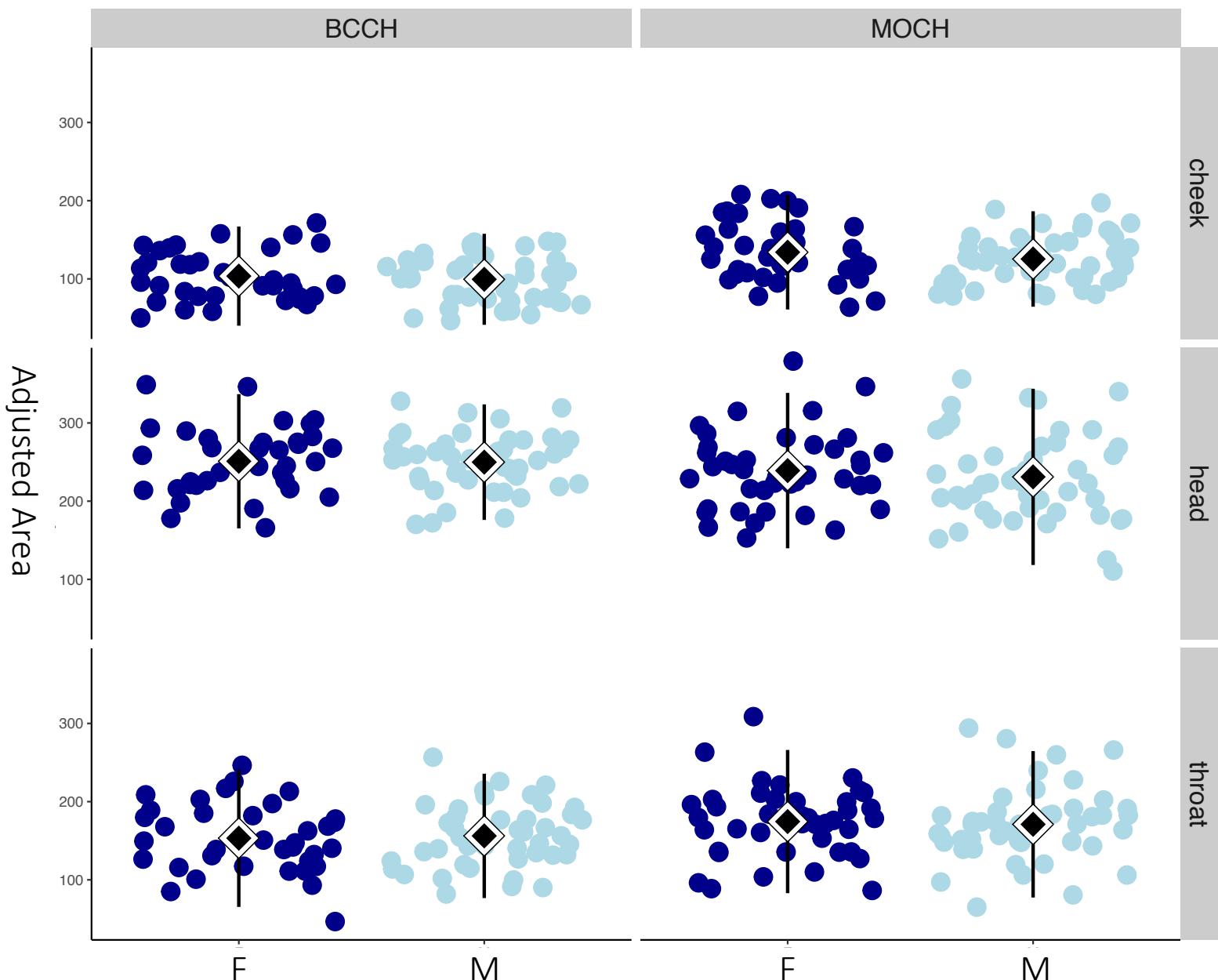
♂



Males and females  
have the same patch  
area in either species.

♀

♂



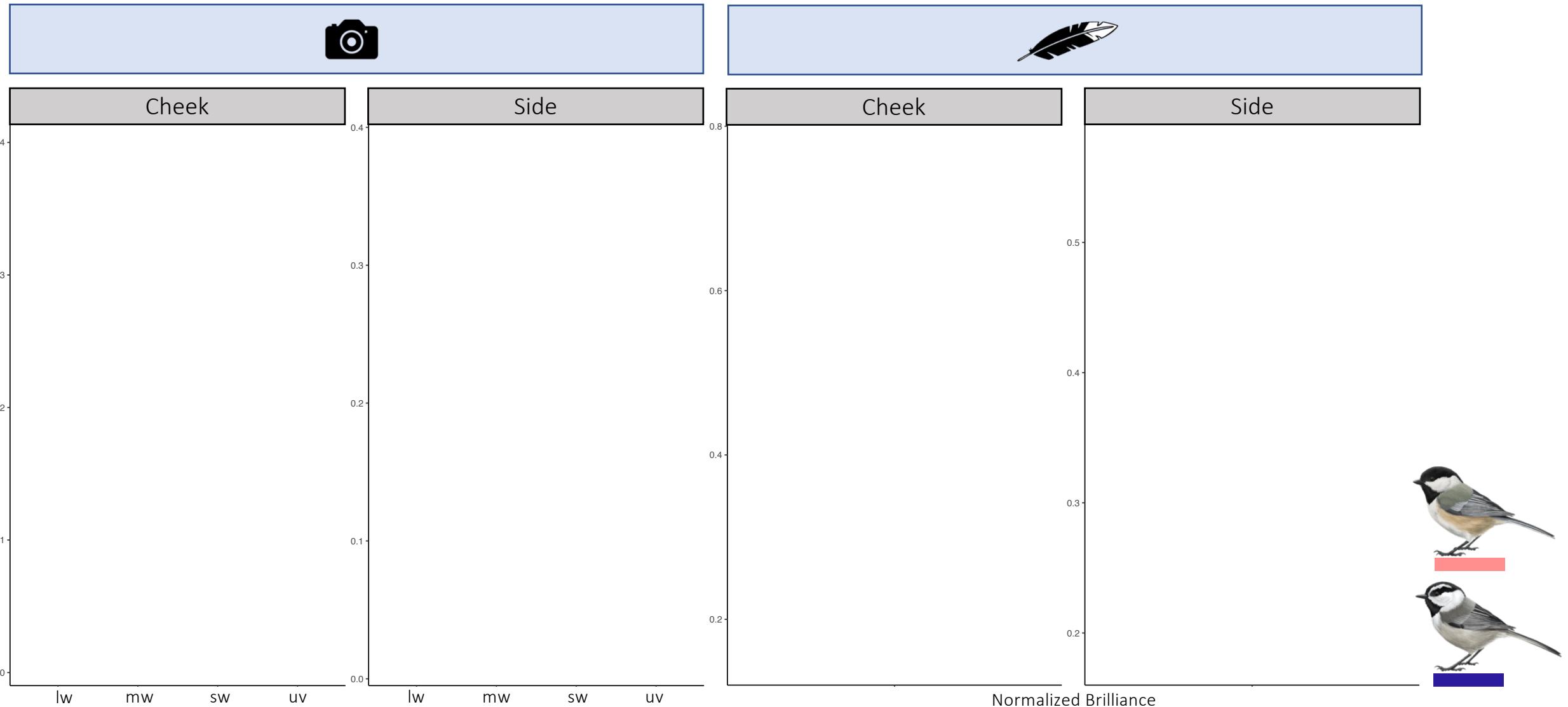
# Plumage Color



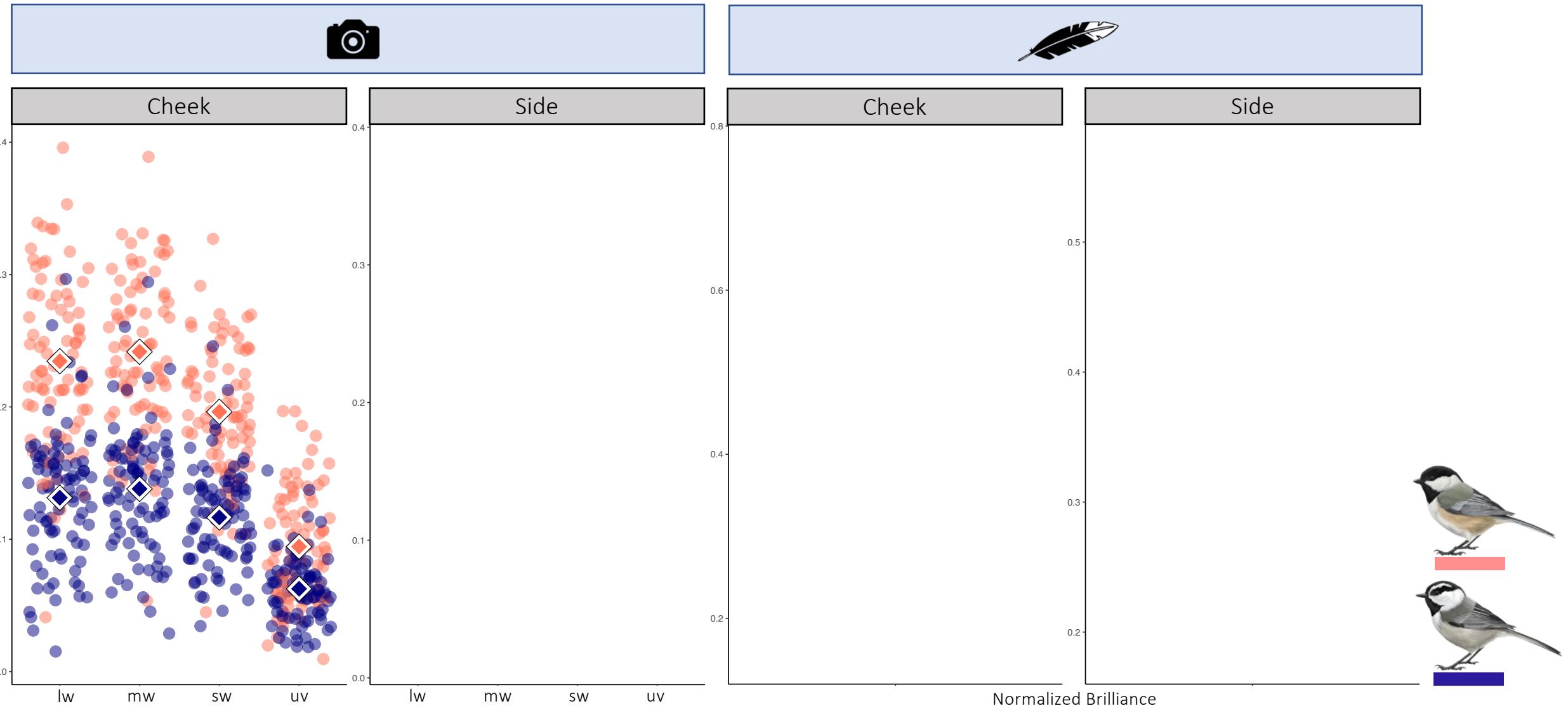
# Species



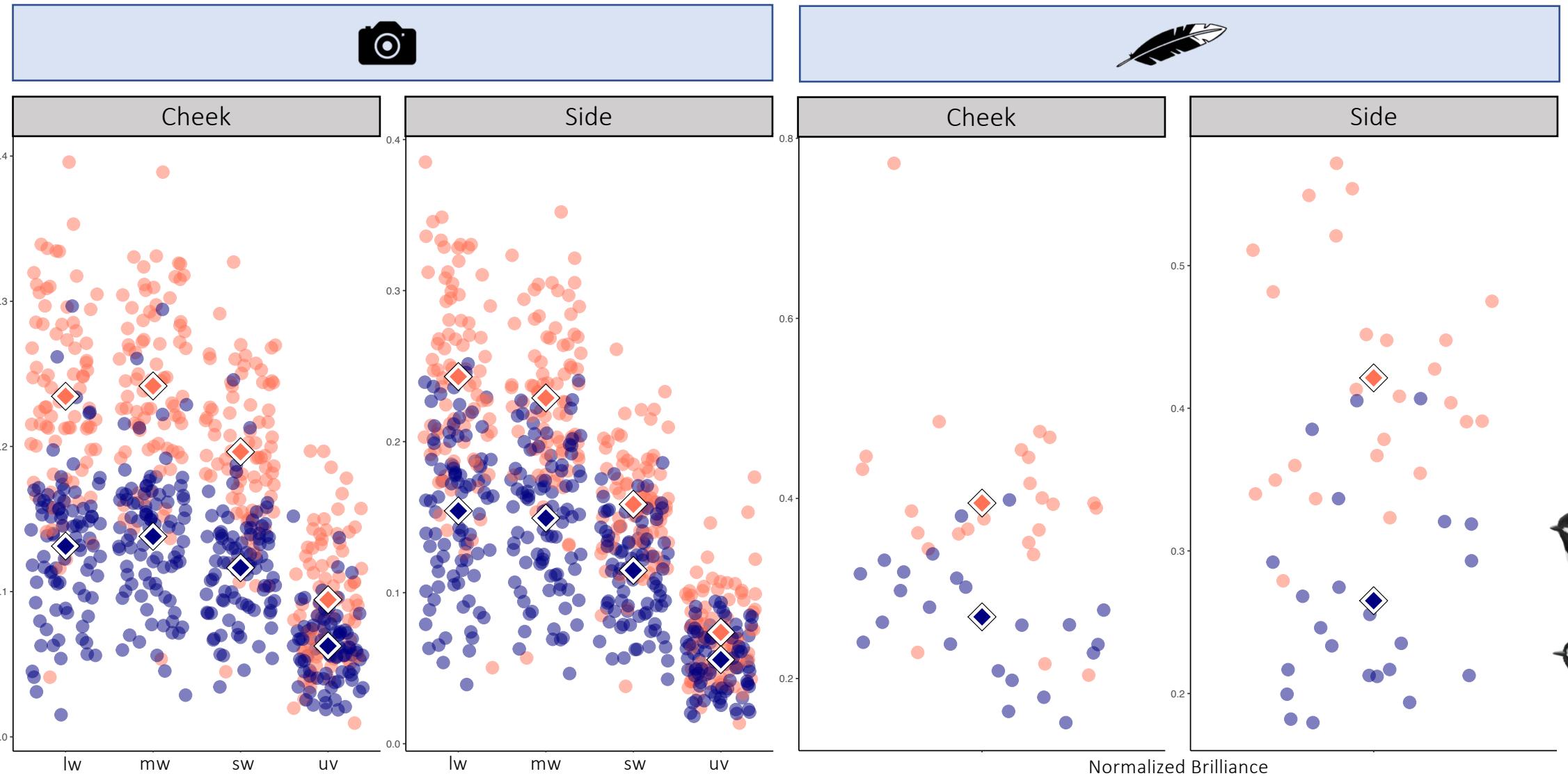
# Black-capped chickadees have brighter plumage.



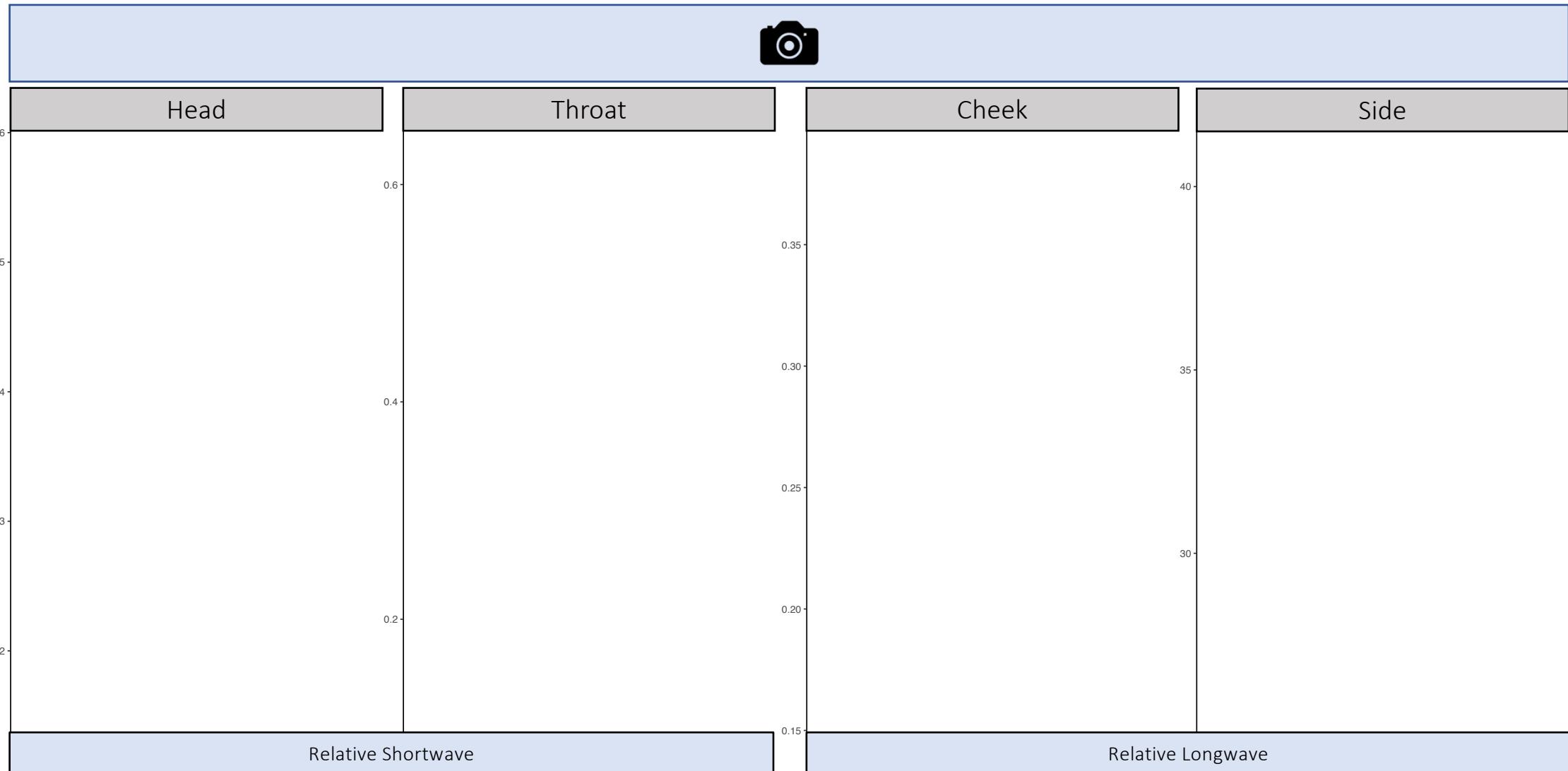
# Black-capped chickadees have brighter plumage.



# Black-capped chickadees have brighter plumage.



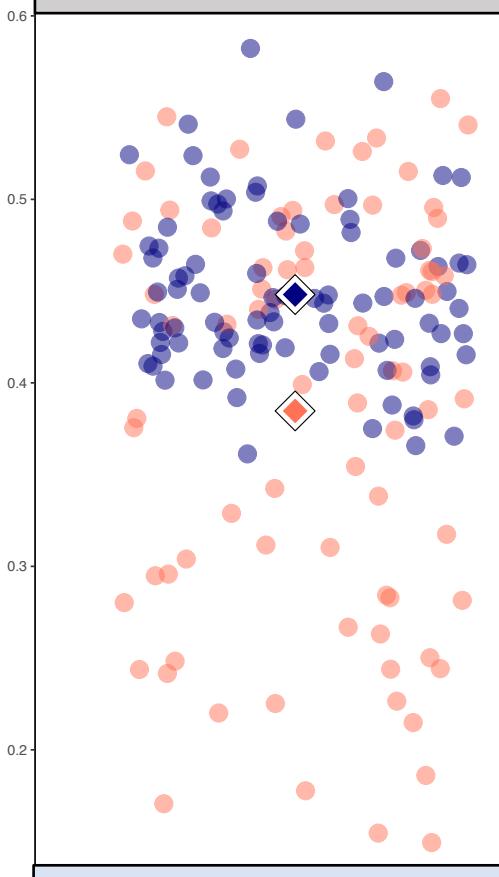
# Black-capped chickadees have warmer plumage.



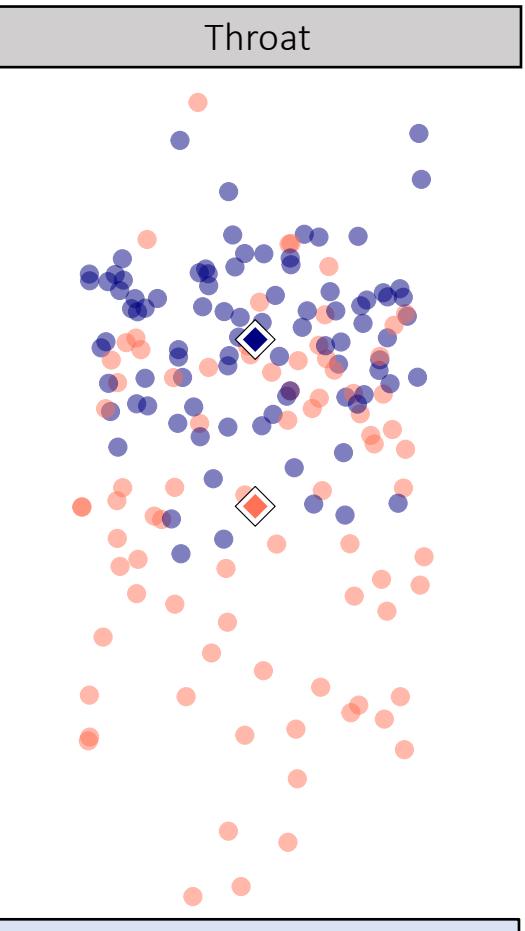
# Black-capped chickadees have warmer plumage.



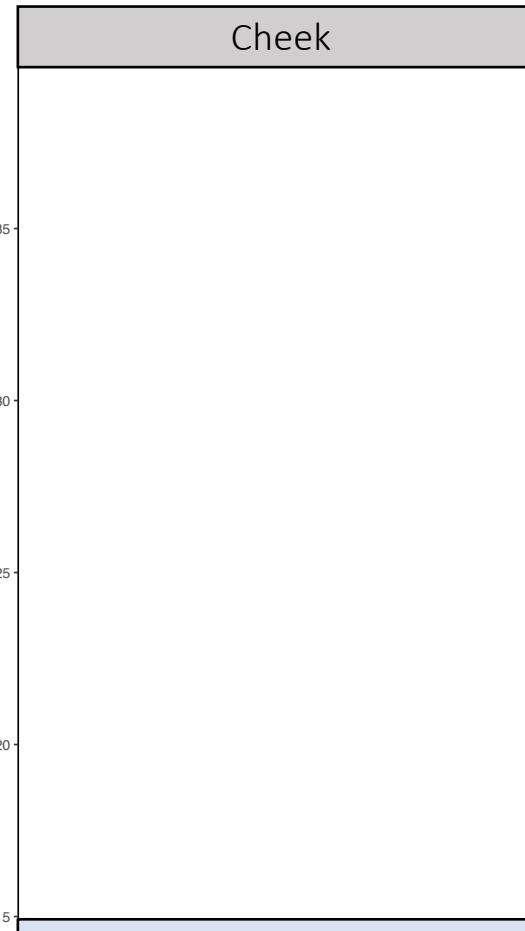
Head



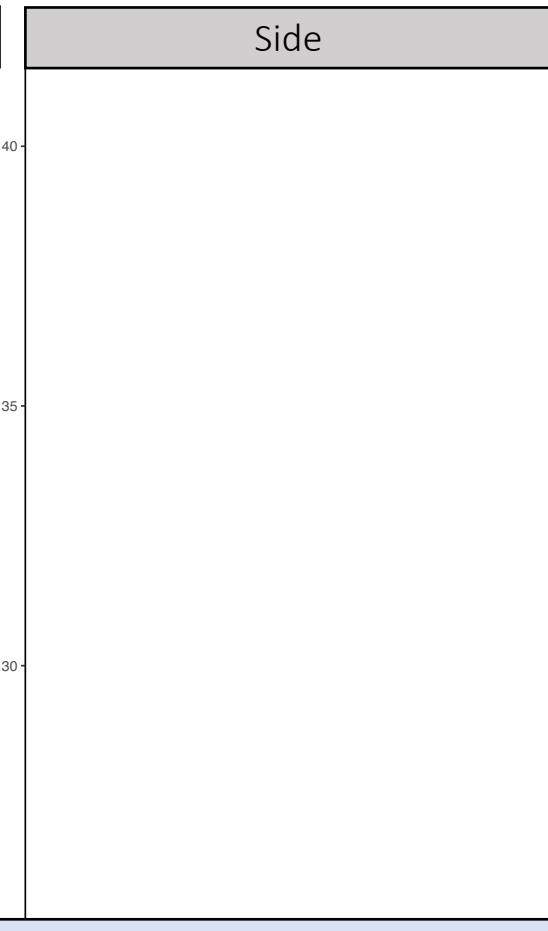
Throat



Cheek



Side



Relative Shortwave

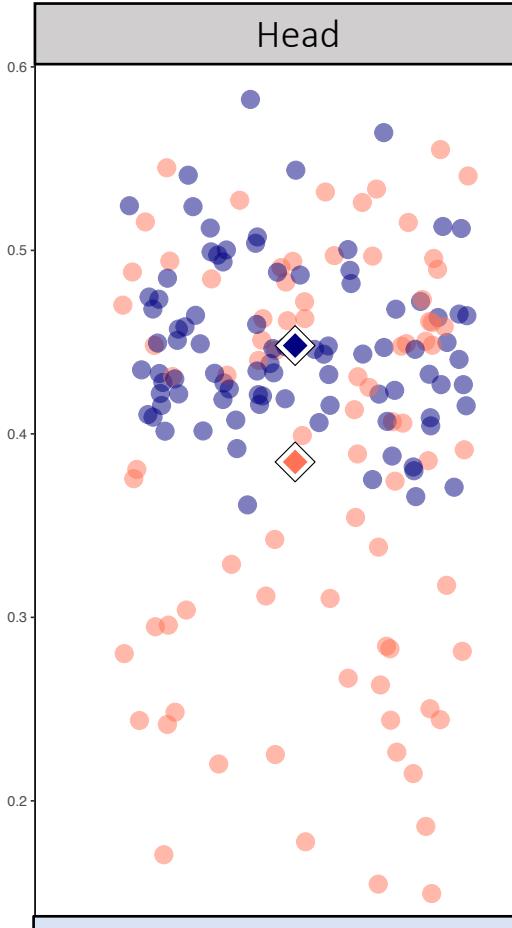
Relative Longwave



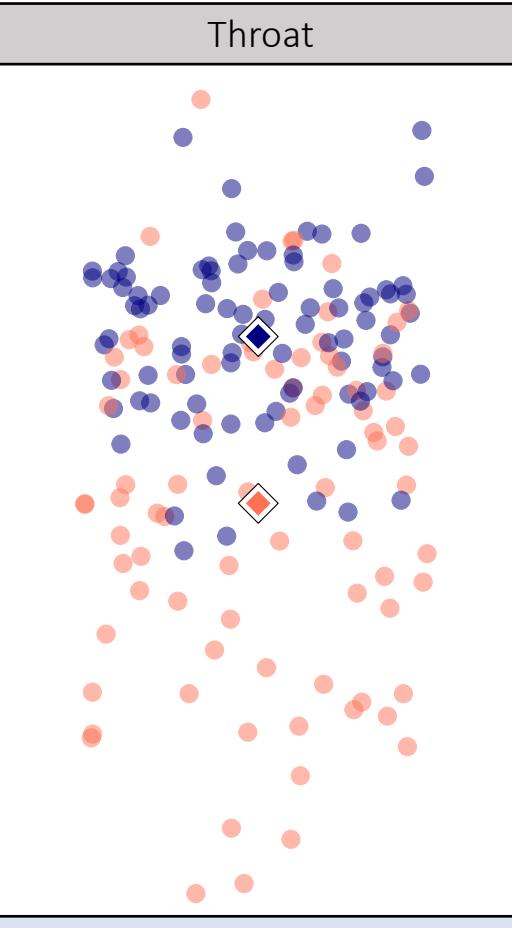
# Black-capped chickadees have warmer plumage.



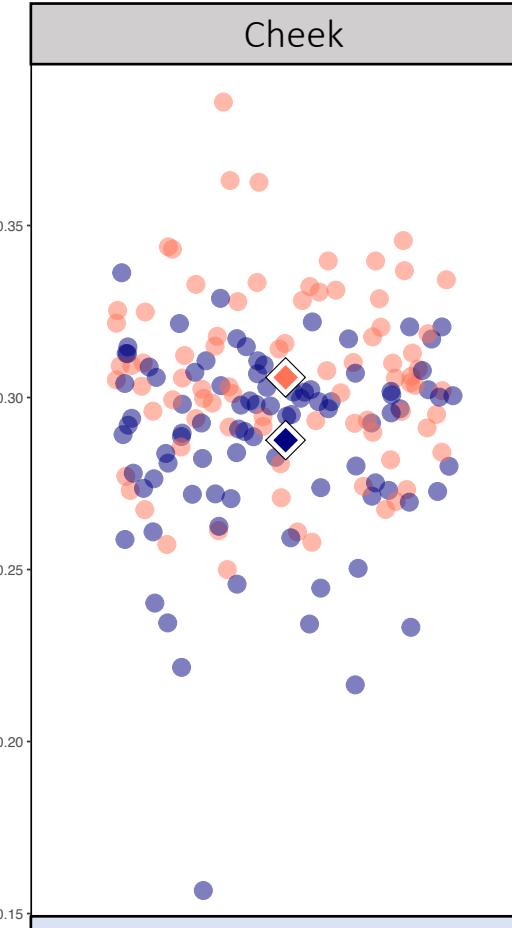
Head



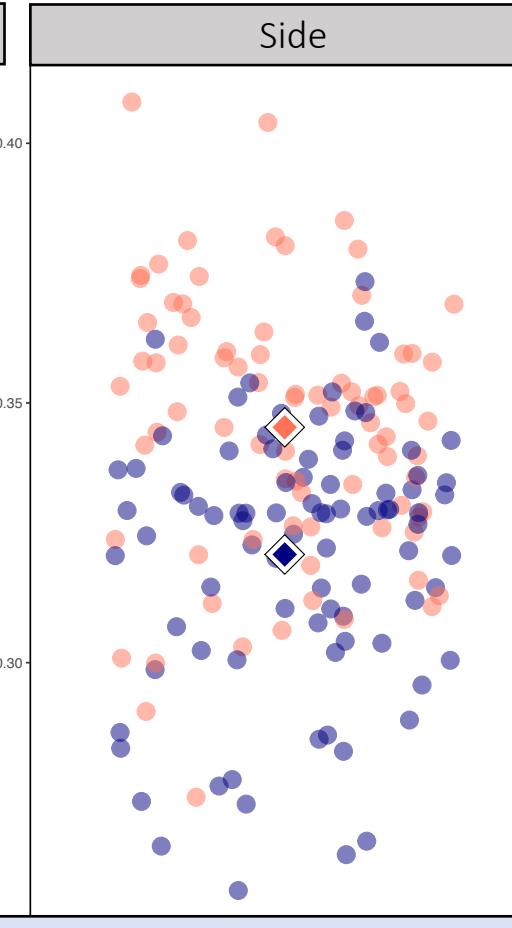
Throat



Cheek



Side

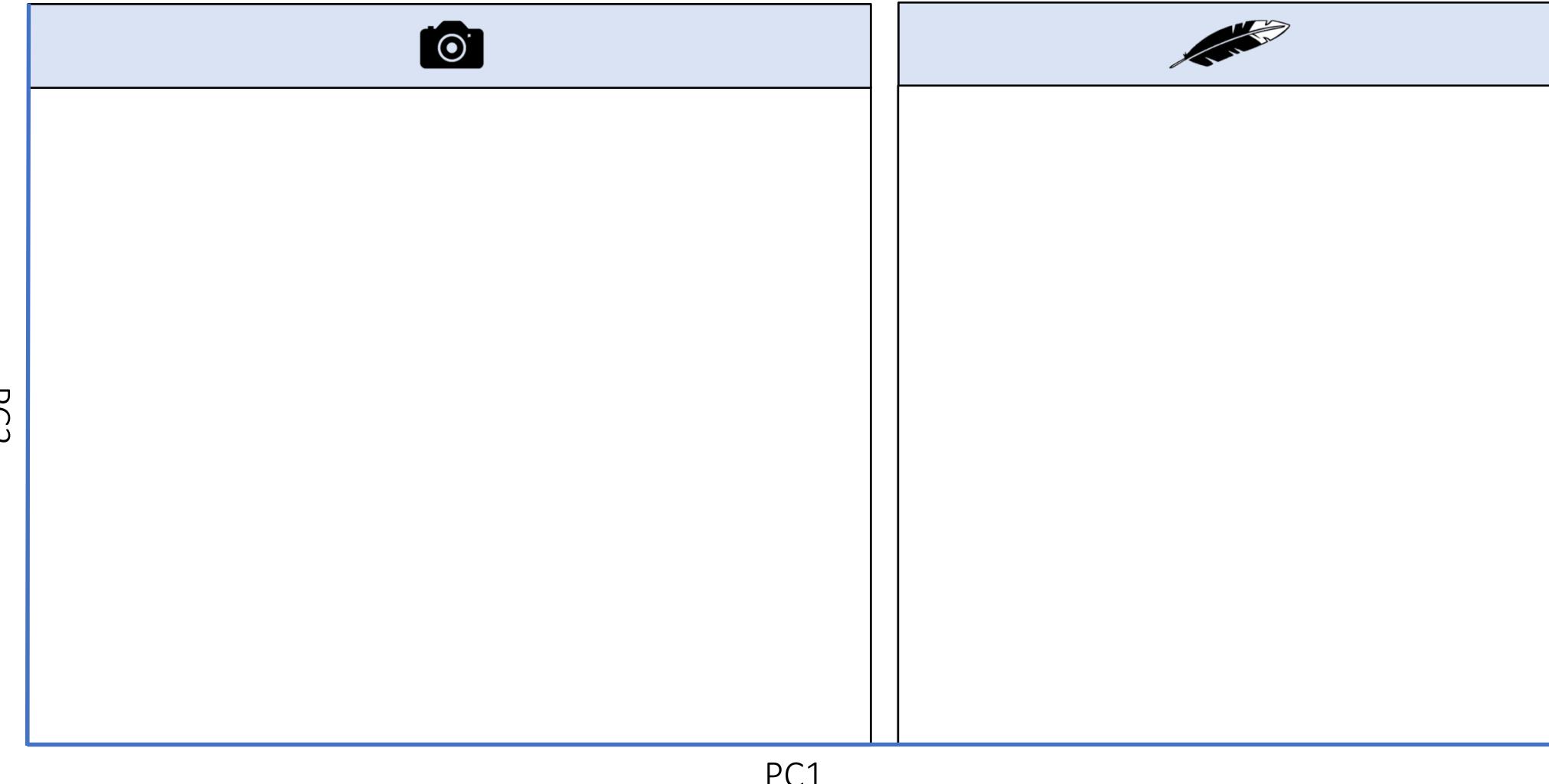


Relative Shortwave

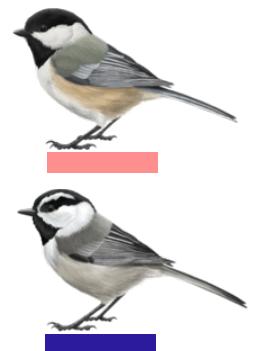
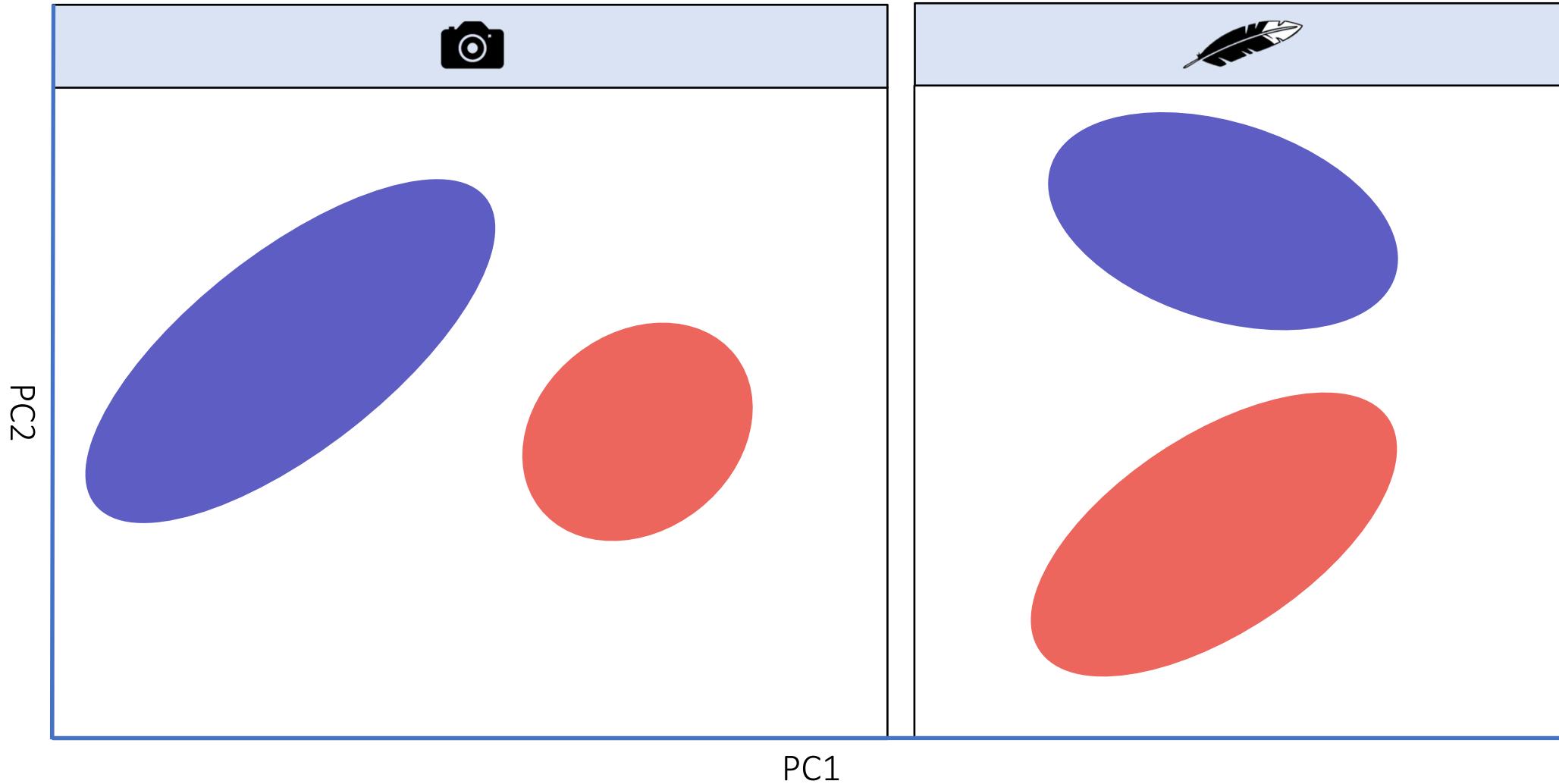
Relative Longwave



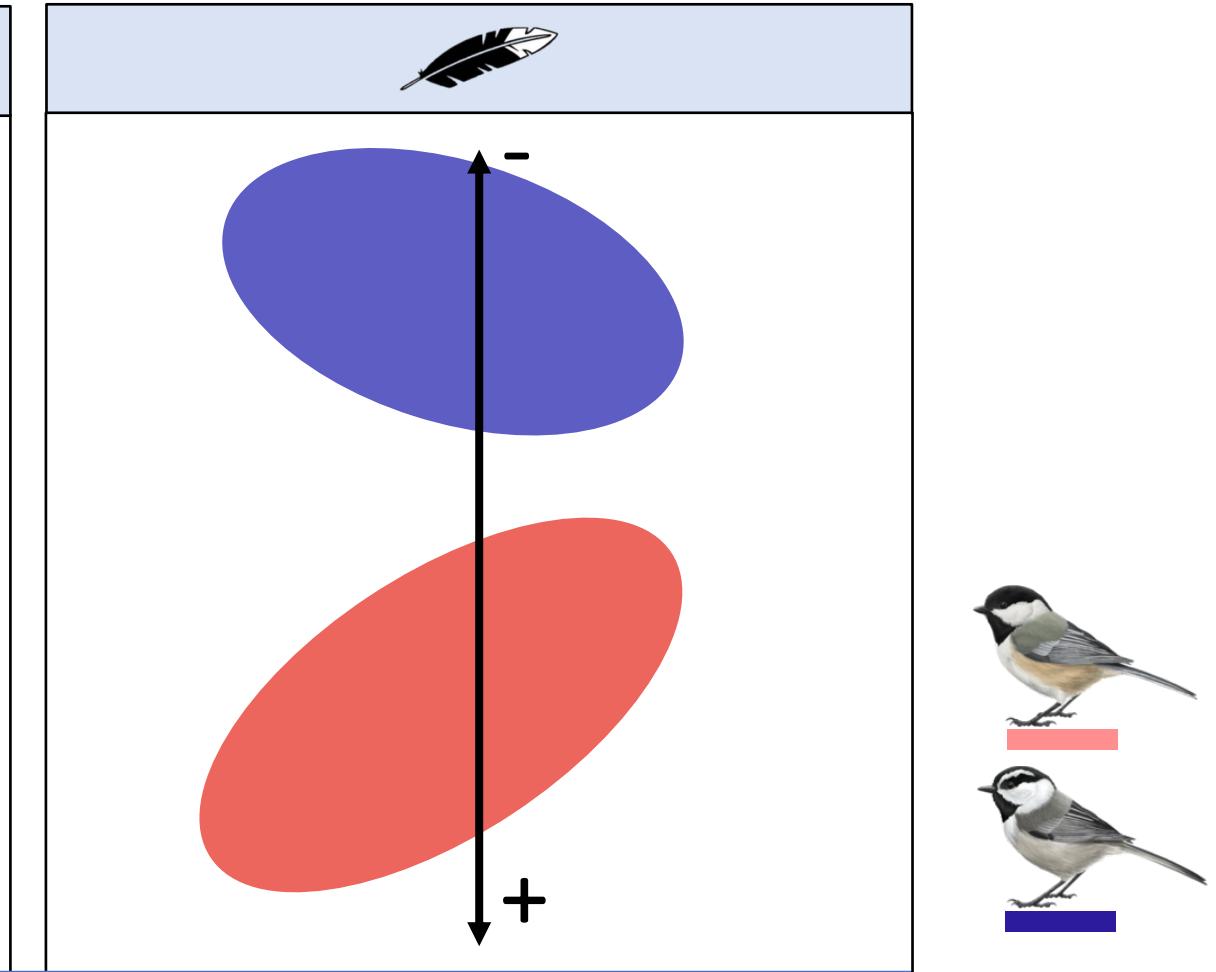
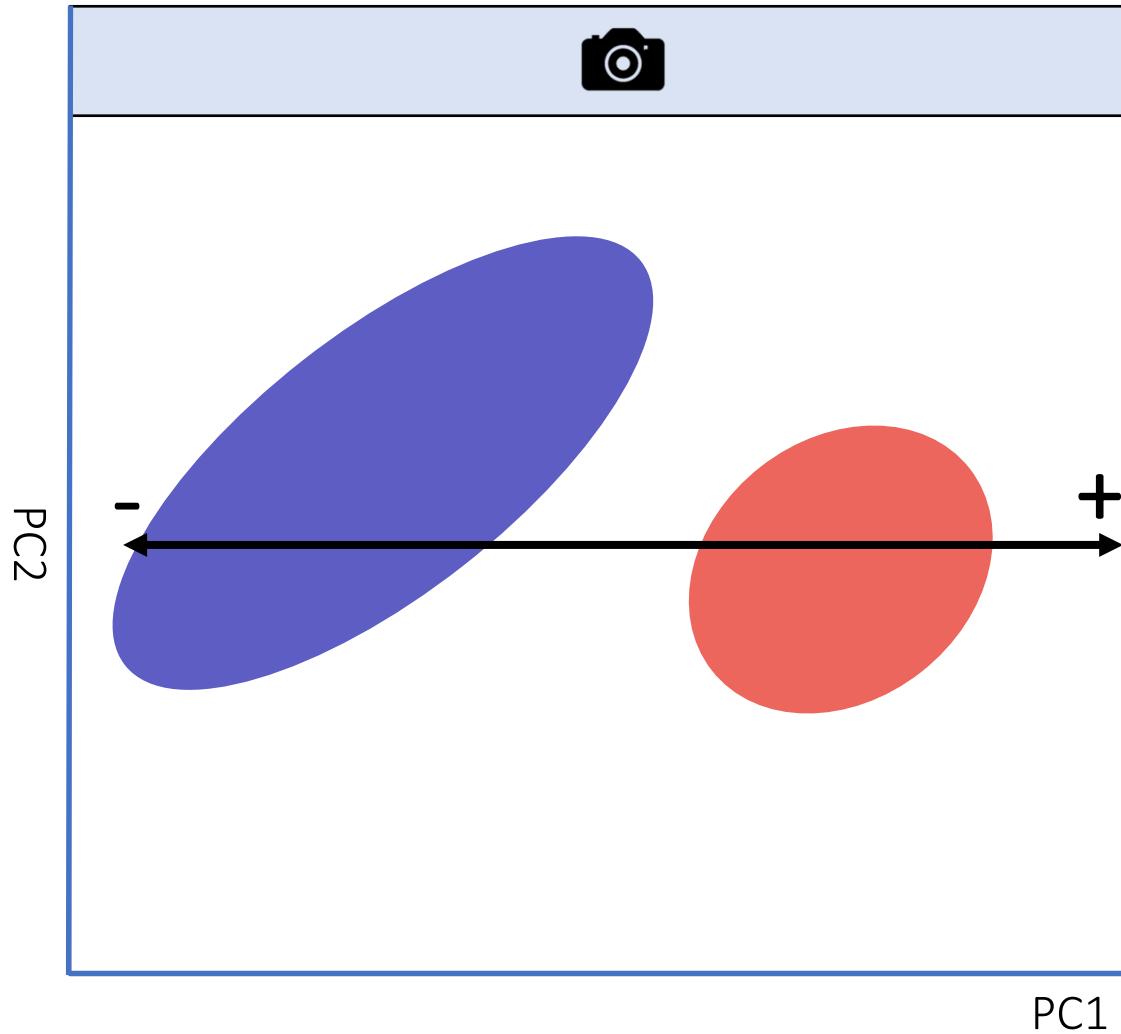
Black-capped chickadees have more color contrast.



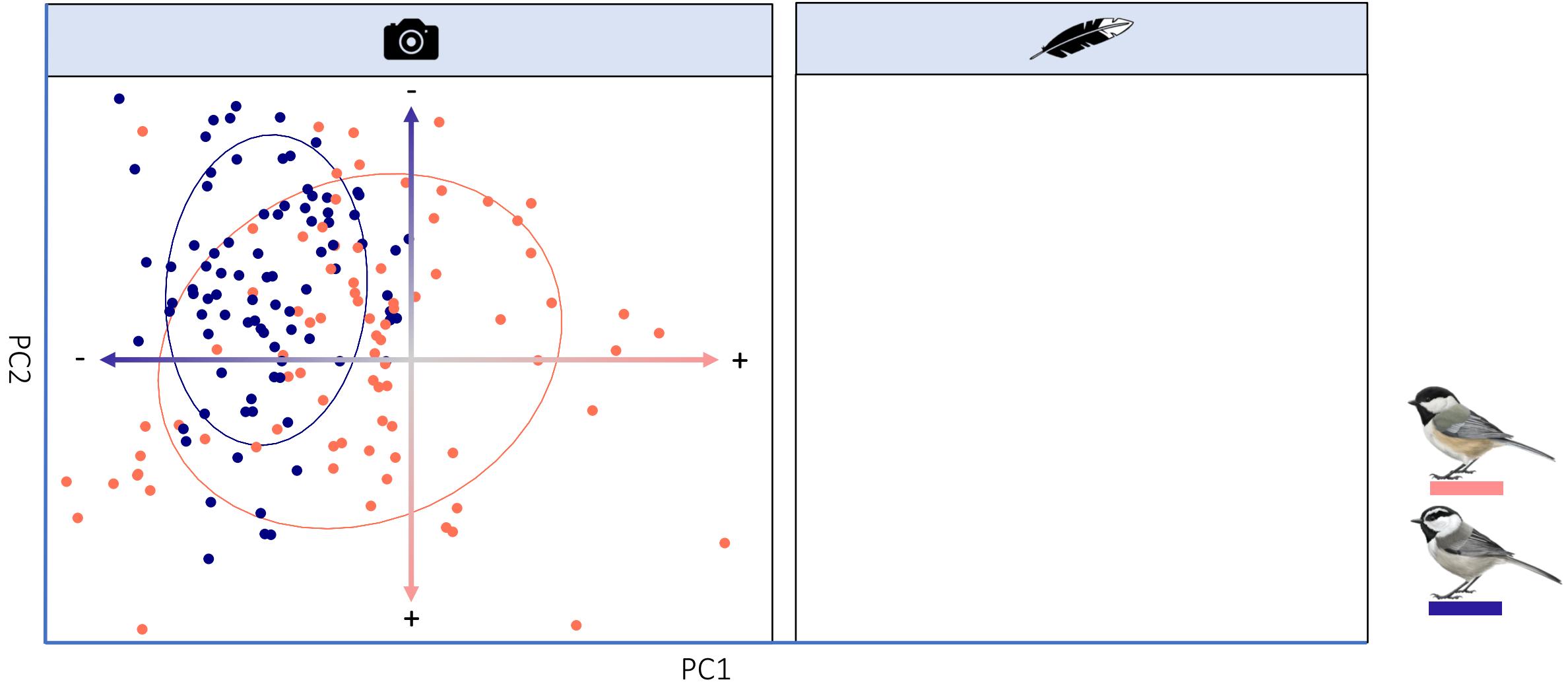
Black-capped chickadees have more color contrast.



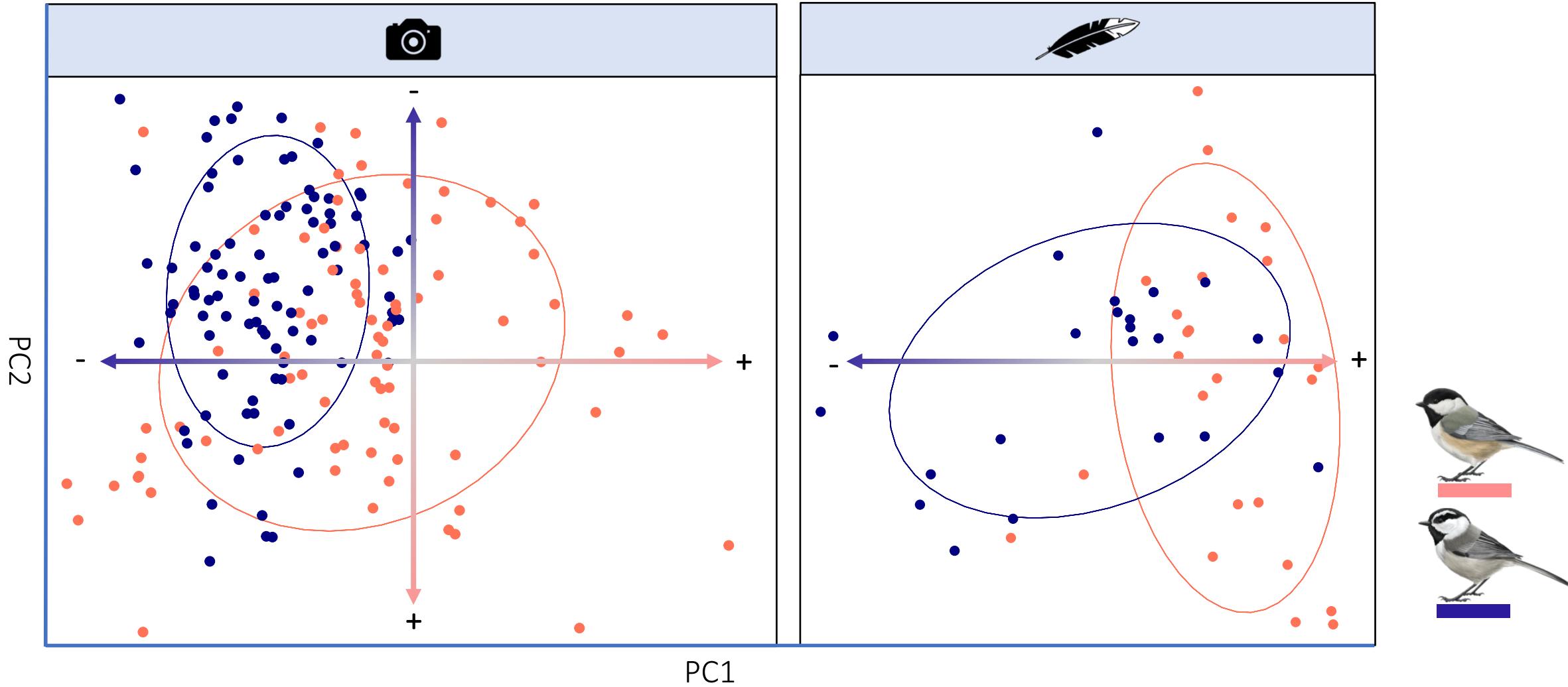
Black-capped chickadees have more color contrast.



# Black-capped chickadees have more color contrast.



# Black-capped chickadees have more color contrast.



# Color patterns between and within black-capped and mountain chickadees.

		BCCH		MOCH		
						
						

	Color
Warmer	
Large Contribution of UV to Hue ( $\phi$ )	
Brilliance	
Different to Trichromat ( $\theta$ )	
Less Contrast	
Greater Contrast	
Cooler	

# Color patterns between and within black-capped and mountain chickadees.

		BCCH		MOCH	
		Male	Female	Male	Female
					
					

	Color
Warmer	Red
Large Contribution of UV to Hue ( $\phi$ )	Orange
Brilliance	Yellow
Different to Trichromat ( $\theta$ )	Green
Less Contrast	Cyan
Greater Contrast	Blue
Cooler	Purple

# Color patterns between and within black-capped and mountain chickadees.

		BCCH		MOCH	
		Male	Female	Male	Female
					
					

	Color
Warmer	Red
Large Contribution of UV to Hue ( $\phi$ )	Orange
Brilliance	Yellow
Different to Trichromat ( $\theta$ )	Green
Less Contrast	Cyan
Greater Contrast	Blue
Cooler	Purple

# Color patterns between and within black-capped and mountain chickadees.

		BCCH		MOCH	
		Male	Female	Male	Female
	head				
	throat				
	cheek				
	side				
	contrast				
	cheek				
	side				
	contrast				

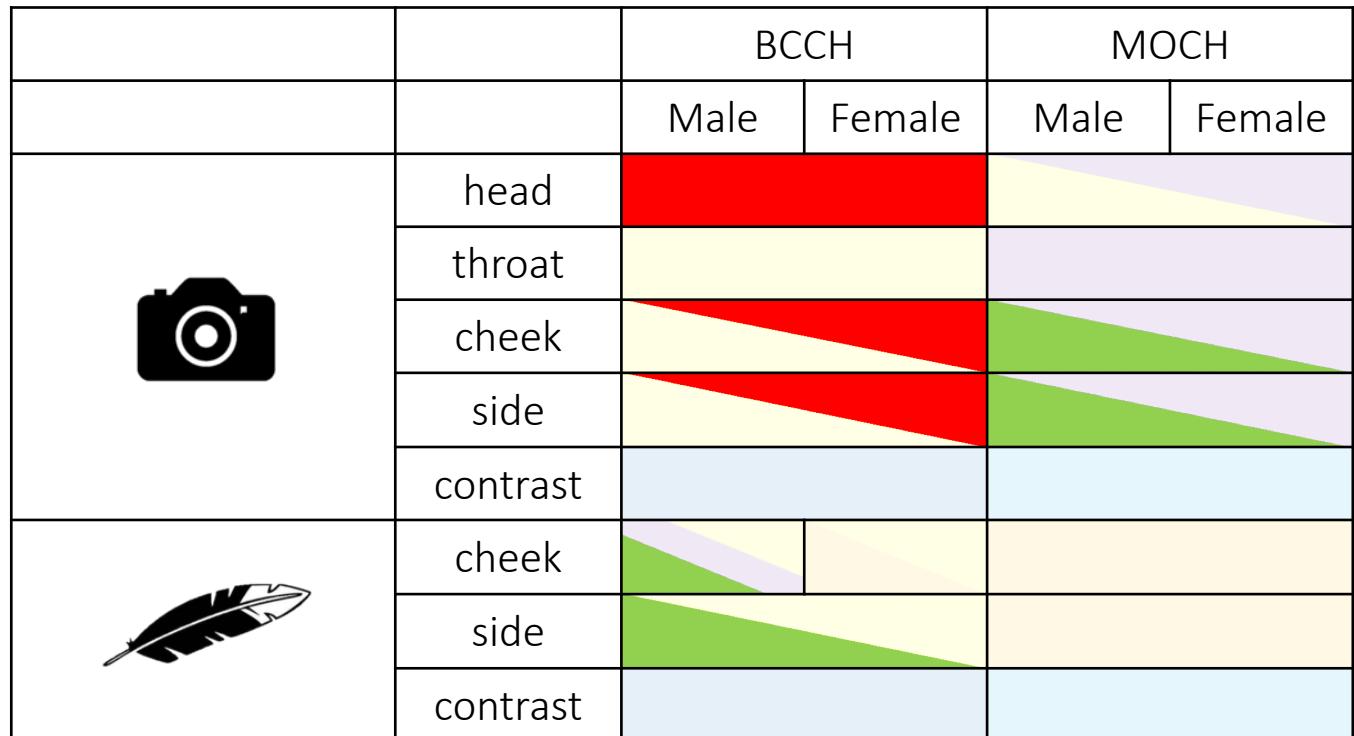
	Color
Warmer	Red
Large Contribution of UV to Hue ( $\phi$ )	Orange
Brilliance	Yellow
Different to Trichromat ( $\theta$ )	Green
Less Contrast	Cyan
Greater Contrast	Blue
Cooler	Purple

# Black-capped chickadees have brighter plumage.

		BCCH		MOCH	
		Male	Female	Male	Female
	head				
	throat				
	cheek				
	side				
	contrast				
	cheek				
	side				
	contrast				

	Color
Warmer	
Large Contribution of UV to Hue ( $\phi$ )	
Brilliance	
Different to Trichromat ( $\theta$ )	
Less Contrast	
Greater Contrast	
Cooler	

# Black-capped chickadees have warmer plumage.



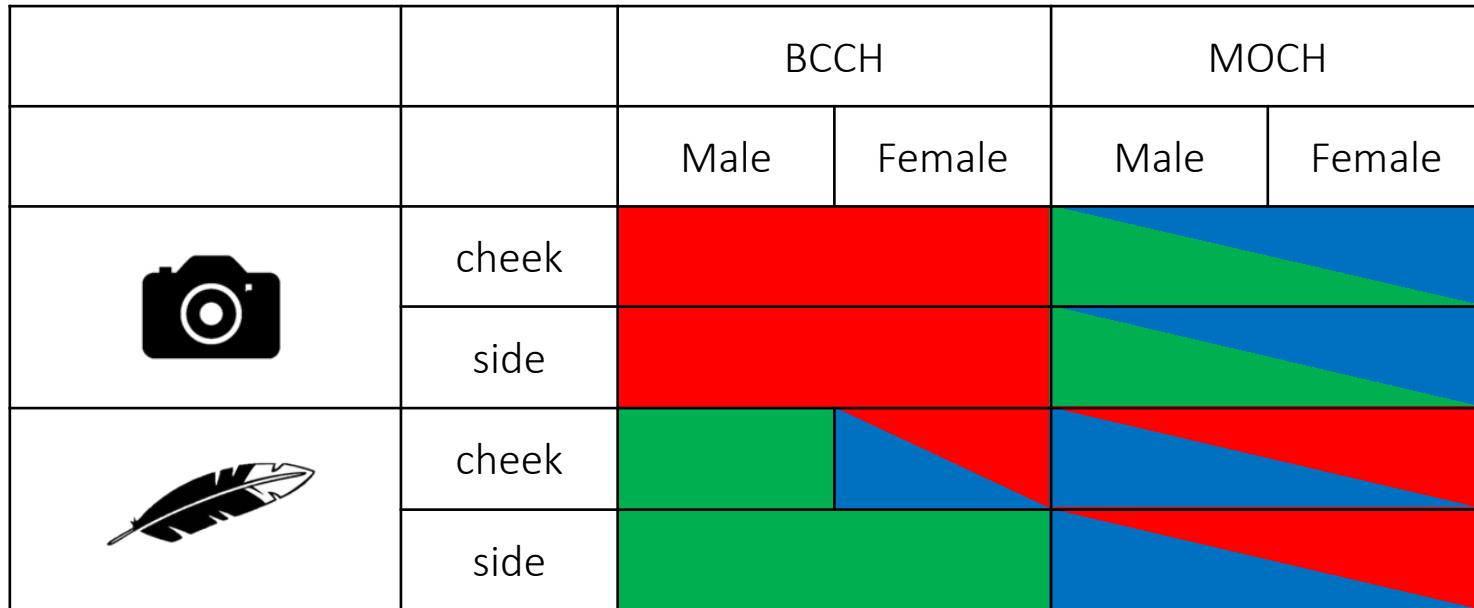
	Color
Warmer	
Large Contribution of UV to Hue ( $\phi$ )	
Brilliance	
Different to Trichromat ( $\theta$ )	
Less Contrast	
Greater Contrast	
Cooler	

# Black-capped chickadees have warmer plumage.

		BCCH		MOCH	
		Male	Female	Male	Female
	head				
	throat				
	cheek				
	side				
	contrast				
	cheek				
	side				
	contrast				

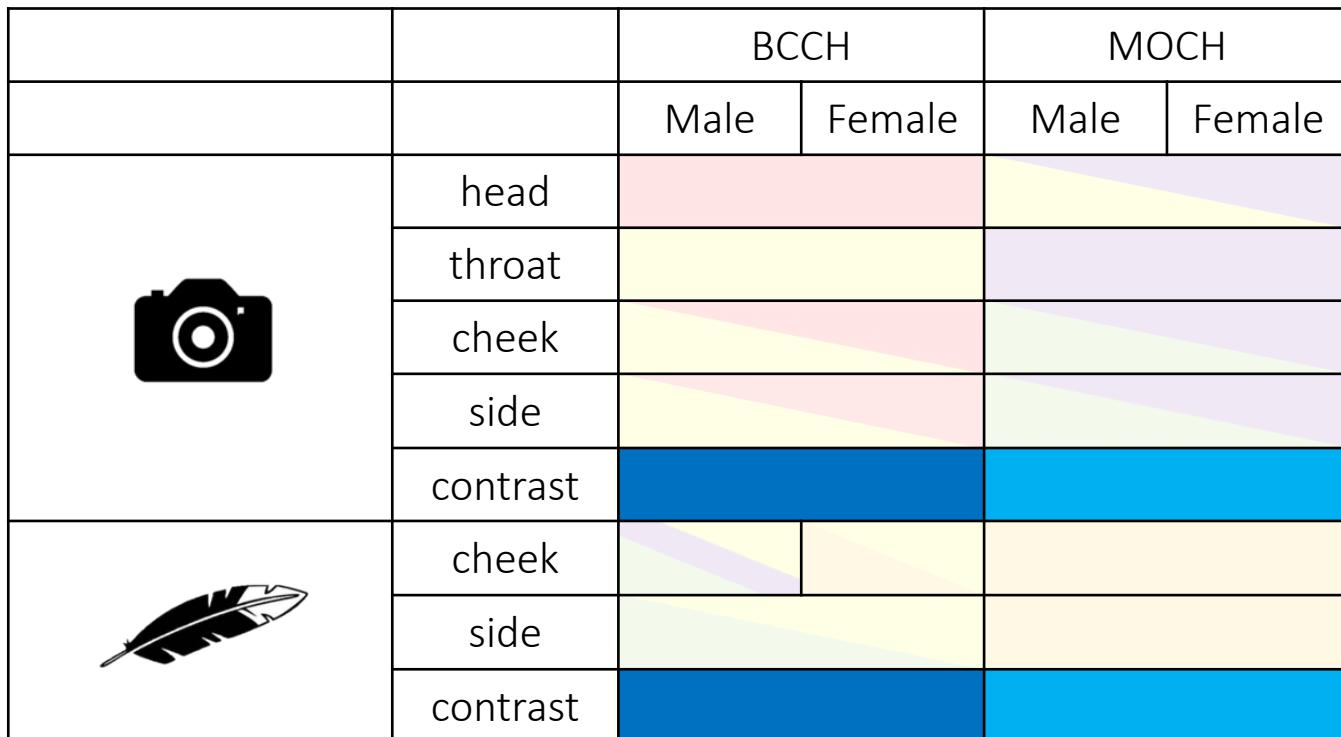
	Color
Warmer	Red
Large Contribution of UV to Hue ( $\phi$ )	Orange
Brilliance	Yellow
Different to Trichromat ( $\theta$ )	Green
Less Contrast	Cyan
Greater Contrast	Blue
Cooler	Purple

Black-capped chickadees have warmer plumage.



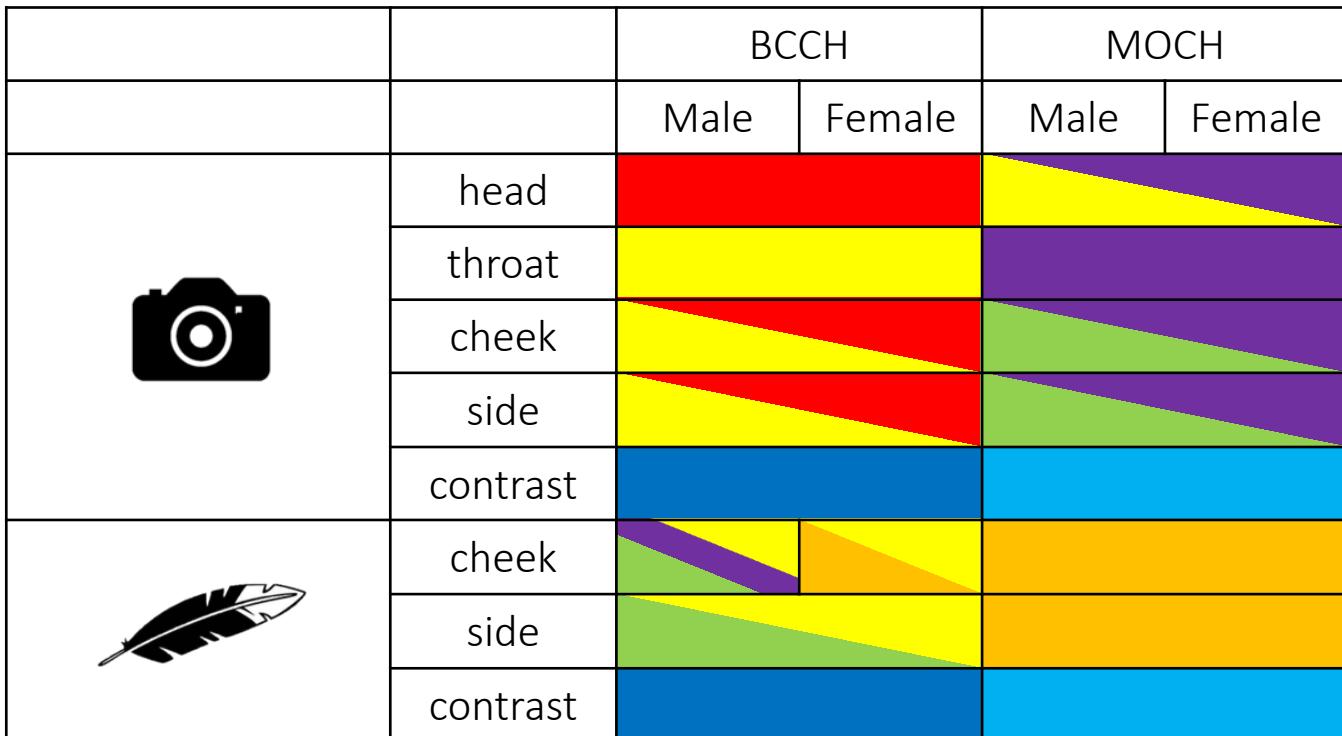
Greater...	Color
Longwave	
Mediumwave	
Shortwave	

# Black-capped chickadees have more color contrast.



	Color
Warmer	
Large Contribution of UV to Hue ( $\phi$ )	
Brilliance	
Different to Trichromat ( $\theta$ )	
Less Contrast	
Greater Contrast	
Cooler	

# Color patterns between and within black-capped and mountain chickadees.

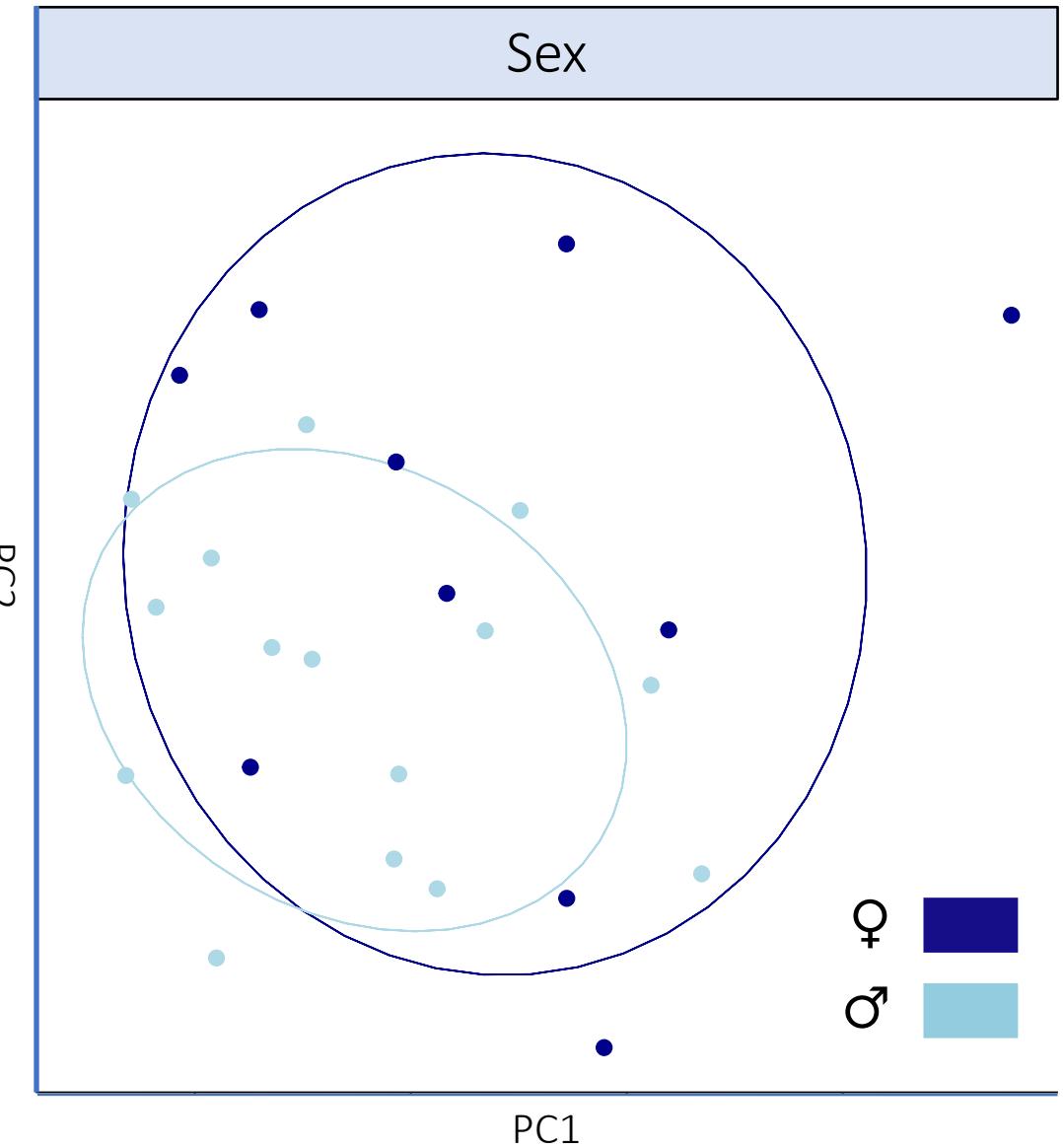


	Color
Warmer	
Large Contribution of UV to Hue ( $\phi$ )	
Brilliance	
Different to Trichromat ( $\theta$ )	
Less Contrast	
Greater Contrast	
Cooler	

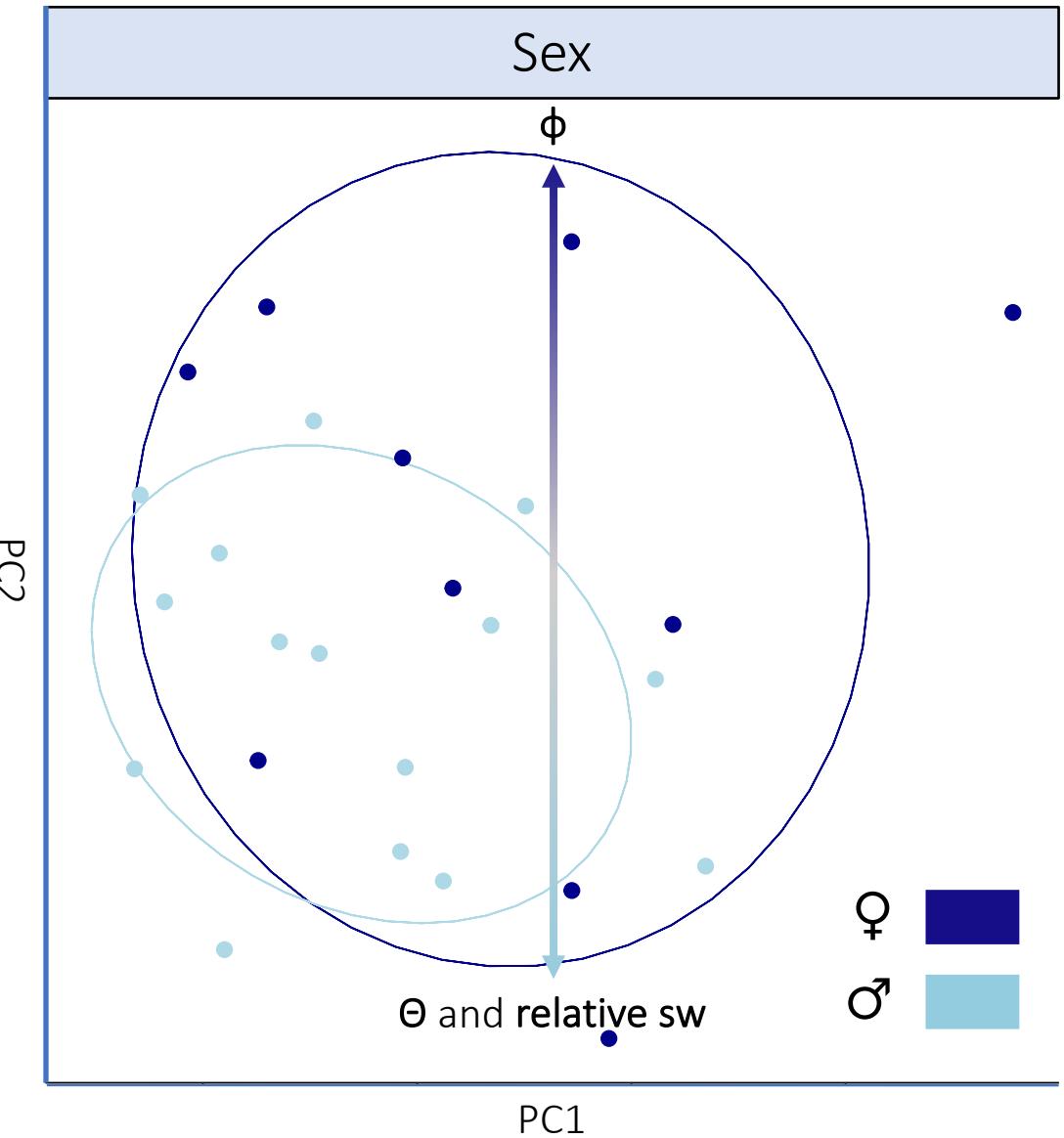
# Sex



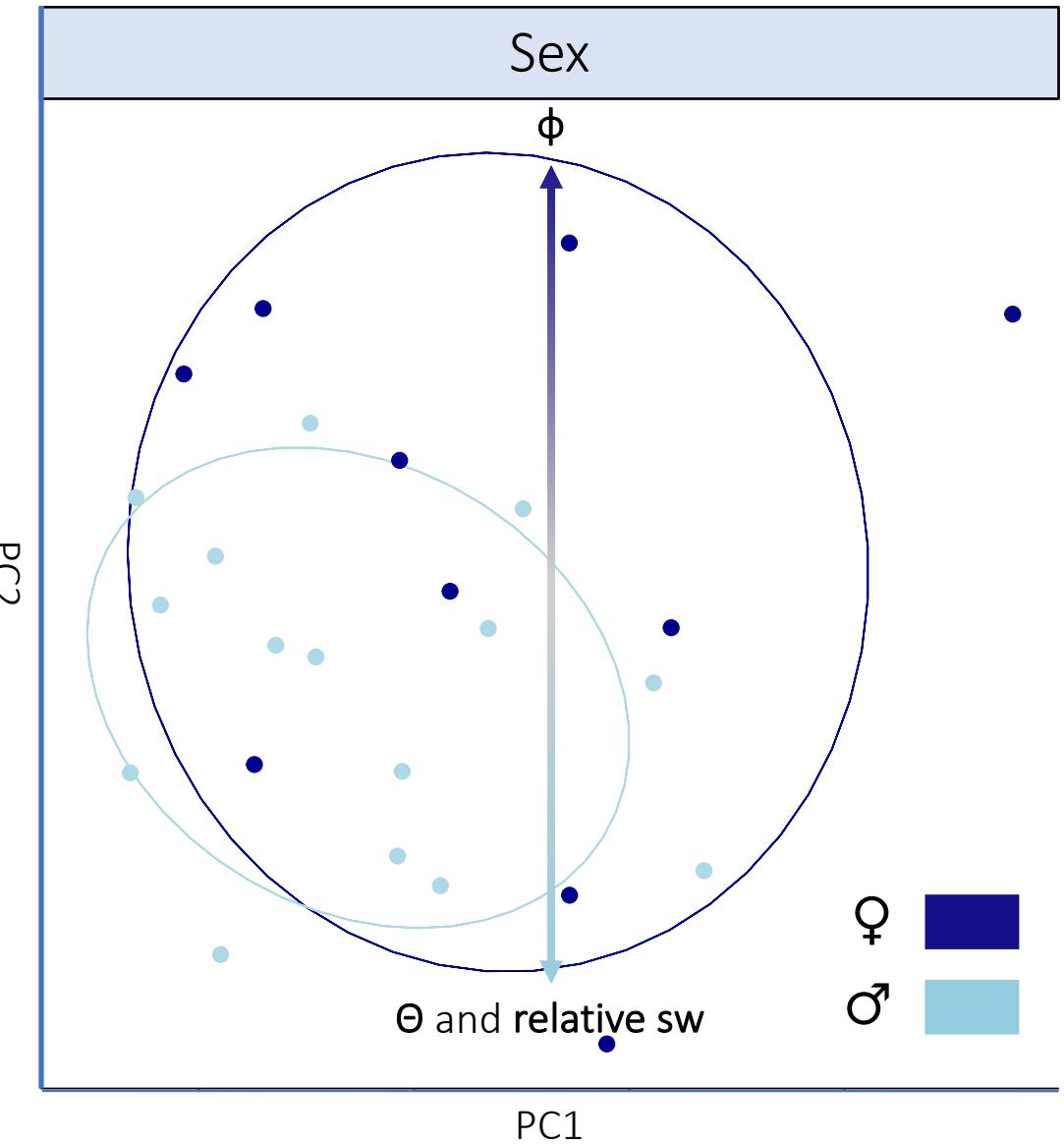
Black-capped chickadees  
are moderately different  
between males and  
females in the cheek.



Black-capped chickadees  
are moderately different  
between males and  
females in the cheek.



Black-capped chickadees  
are moderately different  
between males and  
females in the cheek.



# Conclusions

Black-capped chickadees have brighter, warmer, smaller plumage patches with more color contrast than mountain chickadees.



# Conclusions

Black-capped and mountain chickadees are **morphologically distinct** from an avian perspective.



# Conclusions

Besides a moderate color difference between the sexes in the black-capped chickadee cheek patch...



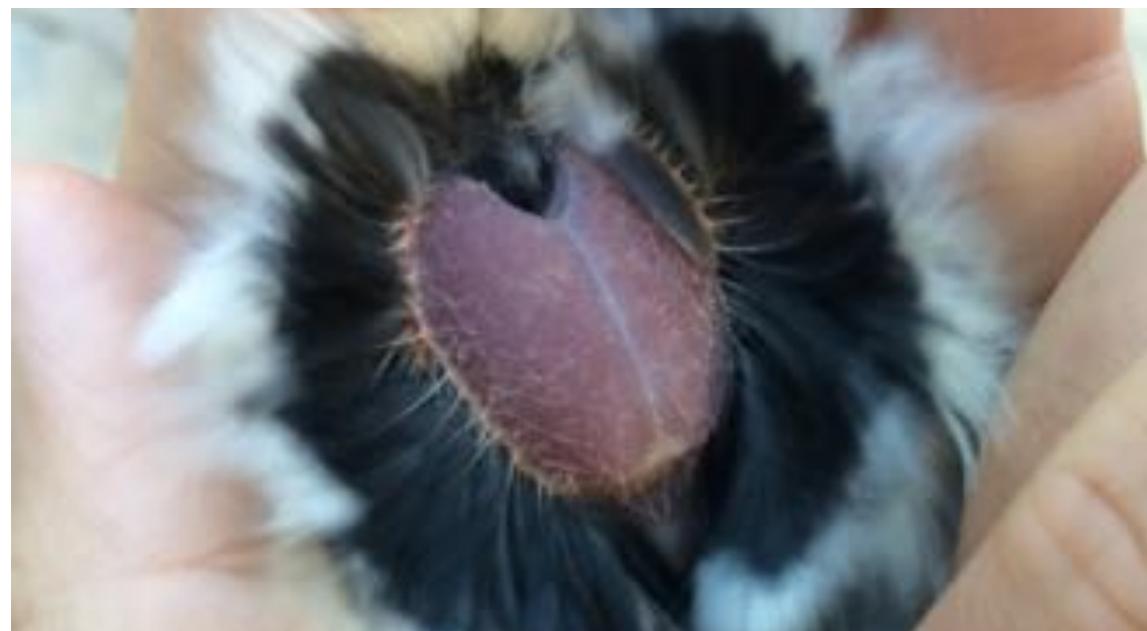
# Conclusions

...males and females are **not** distinguishable by plumage in either species.



# Conclusions

Black-capped and mountain chickadees are **sexually monochromatic** from an avian perspective.



Interspecific differences suggest plumage is  
used for species recognition...

...sexual monochromatism suggests plumage is not used for intraspecific reproductive transactions.

In a study comparing the sexes of 166 song bird species from an **avian perspective**...



Carolina chickadee (*Poecile carolinensis*)

...only 14 species were  
sexually monochromatic.



Carolina chickadee (*Poecile carolinensis*)

Why are so few species sexually  
monochromatic from an avian perspective?



Females mated to males with greater cognitive performance had more eggs and more offspring left the nest.



Is cognition more important for mate selection than plumage?

In *Corvidae*, a family known for its intelligence, many species are sexually monochromatic.



Chihuahuan raven  
(*Corvus cryptoleucus*)



jungle crow (*Corvus macrorhynchos*)

Lee et al. 2012  
AvesNow

# Conclusions

Black-capped and mountain chickadees are [morphologically distinct](#).



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Black-capped and mountain chickadees are *sexually monochromatic*.



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Cognition may be more important than plumage for mate selection in mountain chickadees.



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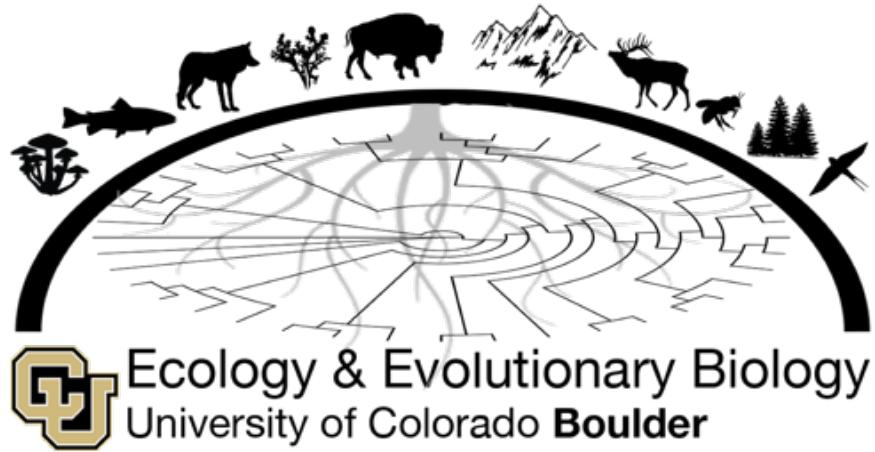
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in mountain chickadees.