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# **Plumage variation in the saltmarsh sparrow**

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## **Abstract**

The purpose of this study was to investigate the proposed idea that certain traits of the saltmarsh sparrow change in appearance over the course of a season. This study also investigated whether such changes differed between sexes. I hypothesized that such changes would prove evident, both over time and between sexes. For this study, saltmarsh sparrows (*Ammodramus caudacutus*) were captured across five sites in Connecticut during the 2011 and 2012 breeding seasons. The saltmarsh sparrows were captured, had their plumage traits scored according to a protocol developed by Shriver et al. (2005), photographed, and released. I conducted scoring based on photographs viewed on computer in a lab setting, in an attempt to see if there were any significant trends in how the sparrows' plumage varied over time or between sexes. Poisson regressions and paired t-tests were used to investigate these hypothesized trends in plumage variation. There ultimately appeared to be no evidence to indicate such patterns, although one analysis suggested that crown definition may increase over the course of a season. I also hypothesized that the scores of some traits would correlate highly with the scores of others, which could allow a simplification of the scoring protocol in which fewer traits need to be scored without any substantial information about the bird being lost. However, no traits correlated with each other to a particularly high degree.

## **Introduction**

Plumage is used to communicate many different types of information between birds in various species. Carotenoid coloration, for example, is used as a means of identification in several species of bird (Brush 1990). UV reflectance of plumage has also been implicated as a method for communicating several kinds of information. Tanner & Richner (2008) found UV

reflectance to be important in parent-offspring interactions; in great tits (*Parus major*), females feed their offspring differently based on the degree of UV reflectance in the feathers of those offspring. Degree and patterns of UV reflectance also play a key role in interspecies recognition (Bleiweiss 2004). Additionally, plumage coloration is an important factor in sexual selection in birds; American goldfinches (*Carduelis tristis*) appear to mate based on the intensity of yellow coloration, forgoing cues like body size (MacDougall & Montgomerie 2003). Bright color displays in male feathers are commonly used among many species of birds to attract females for reproduction. These color displays have been explored in several species; in pied flycatchers (*Ficedula hypoleuca*) (Slagsvold and Lijfeld 1991), common redpoll (*Carduelis flammea*) (Badyaev and Young 2004), house finches (*Carpodacus mexicanus*) (Hill 1990), and many others. Additionally, in the house sparrow (*Passer domesticus*), males with larger display badges - plumage features that communicate information and which often act as a signal of dominance - had more mating success than males with smaller badges (Møller 1990).

There are two primary types of pigmentation in bird plumage; melanin-based and carotenoid-based coloration, each of which is produced differently. Carotenoid pigments, lipid-soluble hydrocarbons, are responsible for an array of colorful hues present in bird plumage (Hill & McGraw 2006). Carotenoid pigments cannot be synthesized by birds or indeed any vertebrates, and therefore must be ingested (Brockmann and Volker 1934). Once ingested, carotenoids are fractioned with lipids, sent to the lymphatic system, and circulate through the blood as part of lipoproteins (Williams et al. 1998). Birds are then able to deposit carotenoids selectively into plumage, likely due to binding proteins that distribute them as necessary (Brush 1990).

Melanin pigments are more abundant in birds than carotenoid pigments, and provide different colors; generally, blacks, browns, and grays (Hill & McGraw 2006). Unlike carotenoids, melanin pigments are synthesized by birds instead of requiring a dietary source (Hill & McGraw 2006). However, the amount of melanin production appears to depend upon the amount of tyrosine present in the diet. House sparrows, for example, when deprived of dietary tyrosine, exhibited decreased blackness in their melanin-based throat patch (Poston et al. 2006). Consumption of certain minerals may also affect birds' abilities to produce and exhibit melanin. For example, manipulation of dietary calcium in zebra finches (*Taeniopygia guttata*) resulted in larger melanin breast patches in the finches that were given more calcium (Hill & McGraw 2006). Synthesis of melanin is reliant on the enzyme tyrosinase, which catalyzes melanin production in all vertebrates (Sanchez-Ferrer et al. 1995). Melanin pigments also appear to be more resistant to fading than carotenoid colorations; Figuerola & Senar (2005) found that in great tits, carotenoid-colored structures varied during a season while the black crown remained the same.

Several environmental factors seem to affect plumage patterns in birds. Past research indicates that environmental toxins affect the pigmentation and feather condition of various bird species. A study by Bortolotti et al. (2003) found that adult male American kestrels (*Falco sparverius*) exhibited duller carotenoid-based coloration when they were exposed to polychlorinated biphenyls. Another study found that yellow plumage in great tits was more vibrant the farther the birds nested from a source of air pollution (Eeva et al. 1998). Yet, research suggests that metal pollution affects different kinds of plumage coloration in different ways. One study found that, although carotenoid coloration diminished with increased exposure to

pollutants, the melanin-based breast stripe in great tits actually became more robust in environments with more pollution (Dauwe & Eens 2008).

In addition to environmental toxins, parasites can affect the plumage coloration of birds. Certain parasites seem to have a particularly strong effect on carotenoid pigmentation. For example, coccidia parasites demonstrate this phenomenon throughout vertebrates through their disruption of the uptake and display of carotenoid pigments. When coccidia infect a host, they cause a thickening of the epithelium that prevents carotenoids from being absorbed properly into the gut (Allen 1987). Passerines are not exempt from this coccidian attack; American goldfinches and European greenfinches (*Chloris chloris*) both exhibited reduced carotenoid coloration when experimentally infected with coccidia (McGraw & Hill 2000; Horak et al. 2004). Feather mites are another parasite that may reduce carotenoid pigmentation in plumage, although there is some disagreement on the matter. Serins (*Serinus serinus*), when treated to kill feather mites, grew more vibrant carotenoid-based yellow plumage when compared to a control group (Figueroa et al. 2003). In contrast, Galván & Sanz (2006) found that mite load correlated positively with plumage yellowness in male great tits.

Environmental factors do not appear to affect both classes of pigments equally, however. Dark melanin coloration seems to be less affected by environmental factors than carotenoid coloration on the whole. A study by Senar et al. (2003) found no link between nutrition and melanin coloration in either house finches or great tits. Melanin expression also appears resistant to parasite activity, at least in house finches (McGraw and Hill 2000). The coccidian parasite, which has a well-researched negative effect on carotenoid coloration in birds, does not appear to affect melanin coloration significantly. One study conducted on American goldfinches found no

significant effect on the size or blackness of black caps in birds infected with coccidia, while the yellow carotenoid coloration suffered significantly (McGraw & Hill 2000).

Many of these environmental factors may apply to the plumage of the saltmarsh sparrow (*Ammodramus caudacutus*). The saltmarsh sparrow, which was recognized as a species distinct from Nelson's sparrow (*Ammodramus nelsoni*) in 1995, lives along the American Atlantic coast in salt marshes (Greenlaw & Rising 1994). Plumage in Nelson's sparrow, the saltmarsh sparrow's close evolutionary relative, is host to environmental contaminants; there is evidence that mercury accumulates in the feathers of Nelson's sparrows when they are exposed to the heavy metal (Winder and Emslie 2011). The saltmarsh sparrow naturally resides in salt marsh habitats and, like Nelson's sparrows, saltmarsh sparrows are exposed to mercury at some sites in their breeding range (Lane et al. 2011). As such, they are subject to have detectable levels of mercury in their blood; another study by Winder and Emslie (2012) found that saltmarsh sparrows had higher levels of blood mercury than either Nelson's sparrows or seaside sparrows (*Ammodramus maritimus*). Metals associated with human industrial activity, such as mercury, are markedly higher in salt marshes located in urban areas, suggesting that sparrows nesting in salt marshes closer to areas of human industrial activity may be subject to higher levels of heavy metal exposure (Sanger et al. 1999).

The purpose of this study was to more fully understand the plumage variation in the saltmarsh sparrow by analyzing variation in the species' plumage between sexes and over time. Learning more about saltmarsh sparrow plumage variation may allow for greater understanding of its behavioral habits and exposure to certain environmental factors. For example, such plumage analysis could further back the finding that the feathers of males and females wear

differently over the course of a season as a result of different reproductive activities (Borowske, unpublished data).

I predict that over the course of the breeding season, the orange face coloration of the saltmarsh sparrow will fade. Conversely, I do not expect to see fading in the dark plumage areas of the saltmarsh sparrow due to the noted resilience of melanin-colored traits. Additionally, I predict that facial coloration in the male sparrows will be brighter than in the females for the purpose of sexual display; this would be consistent with other birds in which males use carotenoid-colored features for the purpose of sexual display.

## **Methods**

The saltmarsh sparrows used for this study were captured from 24 May to 18 October 2011 and from 28 April to 11 July 2012 across five different sites in Connecticut. Those sites were Barn Island Wildlife Management Area (41°20'15.10"N, 71°52'7.05"W), Hammonasset State Park (41°15'36.45"N, 72°33'0.38"W), East River Marsh (41°16'19.49"N, 72°39'9.97"W), Pottagansett Marsh (41°19'5.99"N, 72°12'43.98"W), and Waterford Town Park (41°18'19.61"N, 72° 6'21.23"W).

Bird netting and capture was done systematically across all sites and dates. Netting set-ups differed by season. In the spring, at each location, three sets of two 12 m nets were set up across ditches running through the marsh, perpendicular to the direction of the ditch. These nets were set up shortly after dawn on the capture days. The nets were left up for approximately three hours on each capture occasion. During the summer capture sessions, six nets were set up end-to-end in one continuous string. Nets were checked approximately every 15-20 minutes for bird captures, or immediately after a capture if one was observed. After extraction from the net, each

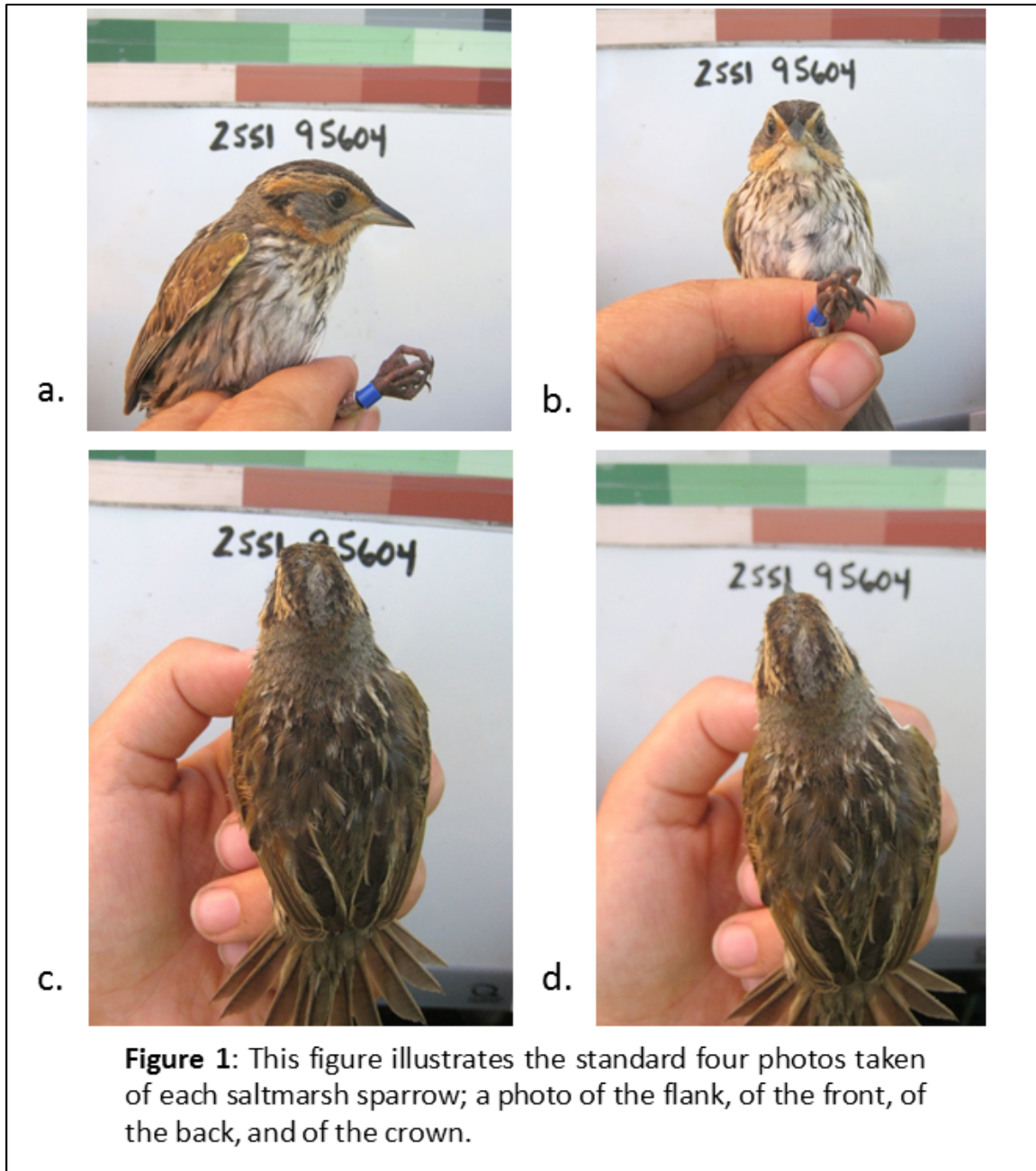


saltmarsh sparrow was photographed so that each could later be evaluated for thirteen characteristics in a laboratory setting. Each saltmarsh sparrow was photographed with a whiteboard backdrop and in the shade for the sake of uniformity in the pictures. All birds were photographed at least once in four different positions against the board; once from the front, once on the flank, once looking down upon the crown, and once from the back. The plumage was later scored in the lab via these photographs. All birds were also identified for their sex. The presence of a cloacal protuberance indicated that an individual was male. The presence of a brood patch indicated that an individual was female.

The plumage of each bird was scored in thirteen separate categories, and a bird could receive a score from 1-5 in each of these thirteen categories. The scoring protocol used was established by Greg Shriver and was developed as a means to distinguish between the saltmarsh sparrow and the Nelson's sparrow (Shriver et al. 2005). The 1-5 scores represent a continuum on which a 5 represents a trait resembling that of a typical saltmarsh sparrow, while a 1 represents a trait that resembles a typical Nelson's sparrow. In the case of face color, 5 represents the peak of orange color around the face, while a 1 represents a dull, yellow-orange color. In the case of the traits involving dark melanin coloration, a 5 represents the boldest, most defined dark colors while a 1 represents poorly defined, gray, diffuse melanin coloration. Each bird was scored on its bill color, the amount of streaking on the breast, the definition of streaking on the breast, the amount of streaking on the flank, the definition of streaking on the flank, the definition of the facial whisker line, the width of that whisker line, the definition of the median crown stripe, the definition of that crown stripe, the color of the face, the definition at the borders of the facial color, the color of the back, and the amount of white streaking on the back (Shriver et al. 2005).

Lab scoring was done on a computer screen indoors, which allowed for zooming in and double-checking of traits.

Statistical analyses were conducted entirely through R version 3.0.1 (R Core Team 2013). Poisson regressions were run to determine the effects of date, sex, and interaction of date and sex on the variation in plumage scores. Analysis on the interaction of date and sex were done specifically to test the hypothesis that males and females wear differently as a result of different rigors associated with reproduction and other field activities. In an alternative effort to see if the sparrows' plumage traits varied with feather wear, scores from birds captured multiple times in a season were compared via paired t-tests. I also used a Spearman correlation to determine how strongly the score of each trait correlates with the scores of other traits.



## Results

With the exception of crown width and crown definition, every trait averaged a score of at least 3.4 (Table 1), putting them towards the saltmarsh sparrow side of the scoring protocol. Crown width and crown definition, however, each had a mean value of under 3 for their average score, putting them closer to the Nelson's sparrow side of the continuum.

<b>Traits</b>	<b>Mean Score <math>\pm</math> Standard Deviation</b>	<b>Minimum- Maximum Score</b>	<b>Median Score</b>
<b>Bill Color</b>	4.02 $\pm$ 1.07	1-5	4
<b>Crown Width</b>	2.83 $\pm$ 0.78	1-5	3
<b>Crown Definition</b>	2.73 $\pm$ 0.83	1-5	3
<b>Whisker Line Width</b>	4.29 $\pm$ 0.75	1-5	4
<b>Whisker Line Definition</b>	4.10 $\pm$ 0.92	1-5	4
<b>Breast Streaking</b>	3.94 $\pm$ 0.93	1-5	4
<b>Definition of Breast</b>	4.06 $\pm$ 0.79	2-5	4
<b>Amount of Flank Streaking</b>	3.52 $\pm$ 0.87	1-5	3
<b>Definition of Flank Streaking</b>	3.77 $\pm$ 0.73	2-5	4
<b>Back Color</b>	3.75 $\pm$ 0.92	1-5	4
<b>Back Streaking</b>	3.44 $\pm$ 0.97	1-5	3
<b>Face Color</b>	4.24 $\pm$ 0.91	1-5	4.5
<b>Face Definition</b>	4.59 $\pm$ 0.59	2-5	5

**Table 1:** Summary statistics for sparrows caught and scored in 2011 and 2012.  
Sample size = 324

None of the plumage traits correlate with another to a particularly high degree (Table 2); the highest correlation was between the score for the amount of breast streaking and the amount of flank streaking, which falls just shy of a value of 0.5.

Traits	Crown Width	Crown Definition	Whisker Line Width	Whisker Line Definition	Amount of Breast Streaking	Definition of Breast Streaking	Amount of Flank Streaking	Definition of Flank Streaking	Back Color	Back Streaking	Face Color	Face Definition
Bill Color	0.062	0.094	0.035	0.081	0.049	0.206	0.037	0.073	-0.022	-0.003	-0.053	-0.026
Crown Width		0.240	-0.074	0.086	-0.105	0.001	-0.017	0.180	0.006	-0.078	0.003	-0.024
Definition			-0.081	0.101	-0.133	0.106	-0.166	-0.105	-0.160	-0.271	-0.144	-0.031
Whisker Line Width				-0.213	-0.074	0.008	-0.116	-0.001	0.035	0.100	-0.069	-0.054
Whisker Line Definition					0.140	0.199	0.138	0.133	0.058	-0.017	0.078	0.061
Amount of Breast Streaking						0.337	0.499	0.203	0.215	0.019	0.080	0.191
Definition of Breast Streaking							0.242	0.355	0.177	-0.105	-0.085	0.072
Amount of Flank Streaking								0.311	0.286	0.144	0.190	0.246
Definition of Flank Streaking									0.227	0.200	0.035	0.064
Back Color										0.223	0.141	0.112
Back Streaking											0.177	0.043
Face Color												0.344

**Table 2:** Results of Spearman correlation analysis showing how strongly the score of one trait correlates with the score of another. Sample size = 324

Despite predictions, the plumage data do not suggest any significant variation in plumage over the course of a season or plumage differences between sexes in the saltmarsh sparrow. A Poisson regression failed to find significant ( $P < 0.05$ ) effects of either factor on variation of plumage (Table 3). Plumage scores of birds caught multiple times in one breeding season also showed no evidence of changing traits with the exception of a significant increase in crown definition (Table 4).

## **Discussion**

After analyzing the scoring data, there does not appear to be any substantive basis for my prior prediction that some traits would change as a result of feather wear over the course of a season or differ significantly between sexes. My predictions, made on the assumption that males and females behave differently in the field in a way that could lead to differential trait expression, is not supported here. Although Borowske found different feather damage between male and female saltmarsh sparrows (unpublished data), that is not reflected in the scores derived from the Shriver scoring protocol.

It is possible that I lacked the necessary data in my attempt to detect plumage patterns. I may not have had adequate statistical power for the analyses I used; however, with 58 birds used for the paired t-tests and 324 birds used for the Poisson regression, so the sample sizes are likely to have been sufficient to detect large differences. The scoring protocol used for this study also may not be capable of detecting subtle changes in plumage, such as may occur over the course of a season. In this case, such change could be occurring, but would be unidentifiable through the methods I employed. It is possible, though, that there is just not any change occurring over the season.

Trait	Intercept		Effect of Date		Effect of Sex		Effect of Interaction of Date and Sex	
	Estimate ± Standard Error	P Value	Estimate ± Standard Error	P Value	Estimate ± Standard Error	P Value	Estimate ± Standard Error	P Value
Bill Color	-0.117641 ± 1.4199773	0.934	0.0001271 ± 0.0001223	0.299	1.3580075 ± 1.5995279	0.396	-0.0001131 ± 0.0001377	0.412
Crown Width	-.6176096 ± 1.555057	0.691	.0001543 ± .0001339	0.249	.1093440 ± 1.796530	0.951	-.00002434 ± .0001545	0.875
Crown Definition	-1.264000 ± 1.72159	0.463	.0001923 ± .0001480	0.194	-.0651887 ± 1.93923	0.973	.000009269 ± .0001666	0.956
Whisker Line Width	1.328510 ± 1.350981	0.325	.00001227 ± .0001165	0.916	-.3768910 ± 1.529178	0.805	0.00003087 ± .0001319	0.815
Whisker Line Definition	.8178004 ± 1.384078	0.555	.00005148 ± .0001194	0.666	.9228651 ± 1.56816	0.556	-.00008008 ± .0001352	0.554
Amount of Breast Streaking	4.17609 ± 1.473982	0.004	-.0002451 ± .0001278	0.055	-.5330190 ± 1.56571	0.747	.00004943 ± .0001463	0.731
Definition of Breast Streaking	.694481 ± 1.42003	0.625	.00005764 ± .0001225	0.638	1.452393 ± 1.59984	0.364	-.0001209 ± .0001379	0.381
Amount of Flank Streaking	2.78099 ± 1.54607	0.072	-.0001346 ± .0001339	0.315	.942506 ± 1.74018	0.588	.00003087 ± .0001319	0.607
Definition of Flank Streaking	1.149207 ± 1.40929	0.415	.00002019 ± .0001216	0.868	.887409 ± 1.60790	0.581	-.00008284 ± .0001387	0.550
Back Color	2.06289 ± 1.40381	0.142	-.00005695 ± .0001213	0.639	1.42819 ± 1.60818	0.374	-.00013256 ± .0001390	0.340
Back Streaking	1.57603 ± 1.47462	0.285	-.00002390 ± .0001273	0.851	.415428 ± 1.68204	0.805	-.00004286 ± .0001453	0.768
Face Color	1.379896 ± 1.39148	0.322	.000002700 ± .0001201	0.982	.150003 ± 1.56660	0.924	-.000009142 ± .0001351	0.946
Face Definition	2.18864 ± 1.34562	0.104	-.000006051 ± .0001163	0.603	-.227301 ± 1.51211	0.881	.00002367 ± .0001307	0.856

**Table 3:** Results of Poisson regression analyses looking at the effects of date, sex, and the interaction of date and sex on each trait scored in lab. Degrees of freedom = 323

	Bill Color	Crown Width	Crown Definition	Whisker Line Width	Whisker Line Definition	Amount of Breast Streaking	Definition of Breast Streaking	Amount of Flank Streaking	Definition of Flank Streaking	Back Color	Back Streaking	Face Color	Face Definition
t Value	1.7293	-0.4402	-3.4948	2.3094	-1	0.5698	0.6473	-0.4217	1.2243	-0.5698	0.9608	0.827	0.2535
P Value	0.0961	0.6636	0.00179	0.02947	0.3269	0.5739	0.5233	0.6768	0.2323	0.5739	0.3458	0.4161	0.8019

**Table 4:** Results of paired t-tests for sparrows captured multiple times in one season. Degrees of freedom = 57

The lack of evidence for plumage changes indicates that feather wear, exposure to environmental contaminants, and other factors do not affect the appearance of the saltmarsh sparrow. It also indicates that males and females do not wear from their activities in the field in a way that differentially affects their scoring. The lack of a significant level of change for the dark, melanin-based traits, is consistent with past research that posits melanin coloration as being resistant to degradation and fading. That lack of significant change is also consistent with my hypothesis that such traits will not suffer a significant level of fading. My hypothesis regarding face color, however, is unsupported; face color did not significantly change, over the course of a season, nor did it differ between males and females. This lack of appreciable change in any of the carotenoid-based traits of the saltmarsh sparrow differs from observations of carotenoid coloration in another species of bird; McGraw & Hill (2004) found that, in male house finches, carotenoid coloration faded dramatically over the course of one season.

The comparisons of birds captured multiple times in one season turned up one significant result of their own; that crown definition appears to increase over the course of a season. This makes sense with regard to the protocol. The protocol describes crown definition as the contrast between the dark lateral stripes on the crown and the lighter stripe in between, with extreme contrast being scored as a 1 and minimal contrast being scored as a 5 (Shriver et al. 2005). If the dark boundaries of the crown stripe did not fade while the lighter plumage of the stripe did fade, that could cause the crown definition to increase while the edges of the crown remained consistent.

Future directions for similar research include further analysis of saltmarsh sparrow plumage. One interesting possibility would be to attempt to link the amount of pollution in saltmarsh sparrows' habitat and bodies to their scoring. Since it is already established that



plumage expression can be affected by environmental pollutants and that saltmarsh sparrows often have significant levels of mercury in their blood (Winder & Emslie 2012), analyzing those two factors together may test if pollutants can affect the plumage of saltmarsh sparrows. However, Borowske (unpublished manuscript) documented significant feather damage in saltmarsh sparrows during the breeding season. In those observations, males suffered more damage to remige feathers and females suffered more from broken rectrices, though the protocol did not detect any changes in plumage; I am therefore unsure whether the protocol is suited to detect changes that contaminants may cause. It may be appropriate to combine the protocol with measures that focus on feather wear in order to develop a more complete picture of plumage change in the saltmarsh sparrow.

I also suggested that the scoring protocol may be simplified if some traits' scores correlated strongly with others. This would allow for quicker and simpler evaluation of birds in the field, minimizing the amount of time birds would need to be handled and stressed. However, no traits correlated with each other to a degree over 0.5, in contrast with my hypothesis. My findings therefore show that streamlining the protocol in the interest of shortening interaction time with birds in the field could result in important information about the birds being lost.

Ultimately, there is little evidence that saltmarsh sparrow plumage coloration varies significantly over the course of a breeding season. The melanin-based traits appeared resistant to variation, which is consistent with the resilience of melanin coloration found in many bird species. However, the carotenoid-based plumage that is often more subject to degradation did not vary either. This suggests that, at least in the saltmarsh sparrow, carotenoid plumage can be similarly resilient over the course of a season.

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