SEASONAL CHANGES IN THE COLOR OF STARLING BILLS[1]

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EARLY in the breeding season the bills of both sexes of the Starling (*Sturnus vulgaris*) become yellow, and upon completion of the breeding season the bills become black. Although other studies (Hicks, 1934; Nichols, 1945) have described the changes in color of the bill, no extensive study on the rate of change is available. The purposes of this study were to determine quantitatively the rate at which the yellow color progresses prior to the breeding season and to determine whether differences, according to age and sex, occur in the rate of color change. I estimated the length of time required for complete color change, and compared the times of the year when the color change occurs in two areas (Baltimore, Maryland, and State College, Pennsylvania). Some information about the time and rate of change from yellow back to black was also obtained. In addition, the rate of growth of the bill was measured in captive birds to compare the rate of color change with the growth.

Bill color and color-control mechanism.—Witschi (1961) reviewed our present knowledge of bill color. In general, two types of pigments, melanins and carotenoids, are found in bills. The melanins, produced in the usual rhizoid-shaped melanophores, become "injected" into epidermal cells that are moving out of the proliferating layer and then become compressed into thin flakes that remain embedded in the cornified cells composing the sheath of the bill. The various yellow, orange, and red carotenoids are not synthesized by the bird but are absorbed along with other foodstuffs. The mechanism by which the carotenoids are selectively acquired by certain structures, such as the bill, is not known. Extractions of carotenoids in the Starling show that they are present the year around, although yields are highest during the breeding season. By castration and hormone injections, it has been shown that the yellow bill color is a specific indicator of the presence of androgens (Witschi and Miller, 1938). The amount of androgen necessary to cause the bill to become yellow in the Starling is not known. However, Hilton (1958) reports that, in male Starlings, enough androgen (testosterone) has been secreted by the time the testes weigh only 30 mg to change the color of the bill completely.

Not all Starlings have yellow bills during the breeding season. For example, Hicks (1934) reported that two to four per cent of the Starling population that he studied in Ohio in the breeding season did not have yellow bills. Hicks claimed that these birds were primarily non-breeding birds, diseased or immature, and usually females.

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TABLE 1

CHARACTERISTICS OF COLOR CLASSES OF STARLING BILLS OBSERVED AT BALTIMORE, MARYLAND, FROM 1954 TO 1958

Color class	*Description*
0	Bills completely black; rami of bill black in both sexes.
1	Bill one-third yellow, progressing from the basal region; bases of rami in males begin to appear blue to blue-black; bases of rami in females begin to appear pale pink.
2	Bill two-thirds yellow, only tip black; base of rami in males, blue to blue-black; base of rami in females, pale pink.
3	Bill completely yellow; rami as in color class 2.

METHODS

Progression of yellow pigment in bills.—Information on color of Starling bills was collected at Baltimore during banding studies by D. E. Davis and associates from 1952 to 1959. Age and sex were determined by the methods described by Davis (1959). Only definitely subadult and adult birds were analyzed. Indeterminate birds that fell between these categories were not analyzed. The amount of yellow in the upper mandible was recorded by color classes (Table 1). Data collected from October to March from 1954 through 1958 were used for an analysis of bill coloration. In the other years few birds were captured or the collections were not frequent enough to warrant analysis of the data. The data were tallied by age and sex for every half-month. Early October was chosen for the beginning of the analysis, since all but a few birds had completely black bills at this time. The last collection in March was used as the termination, because the birds began to breed at this time and records were sparse from April through the summer months.

Average color classes were determined for each half-month from October to March for each of the four years, and an average for the four years was determined. Although the numbers of birds collected and the dates of the collections were not the same each year, the average color classes for all age and sex categories of each year appeared to be the same for closely corresponding dates. Hence, by combining the data for the four years (1954–1958), a good sample was obtained to show the progression of yellow with time by age and sex. Coefficients of correlation were determined for each age and sex category by using the form of Alder and Roessler (1960: 158). Next, these coefficients of correlation were tested for a linear relationship of the data by a t-test as given in Alder and Roessler (1960: 163). Standard deviations of the color classes were determined for each date and were found to be essentially the same. Since the first point started through the origin, and all the color classes had essentially the same standard deviation (Deming, 1943), equations for the progression of yellow color were determined in the form, $C = b\ T$, where C = color, b = slope of the line, and T = time in days from the first change. The slope of the line was calculated by using the formula given by Deming (1943: 32). The estimated standard error of the slope was determined by using the formulas outlined in Snedecor (1956: 141). The t-test was used to test for difference in slopes of the regression lines by age and sex (Snedecor 1956: 136).

Disappearance of yellow in bills.—Starlings were collected near State College, Pennsylvania, in the summer and fall of 1961 to determine the rate at which the bill again

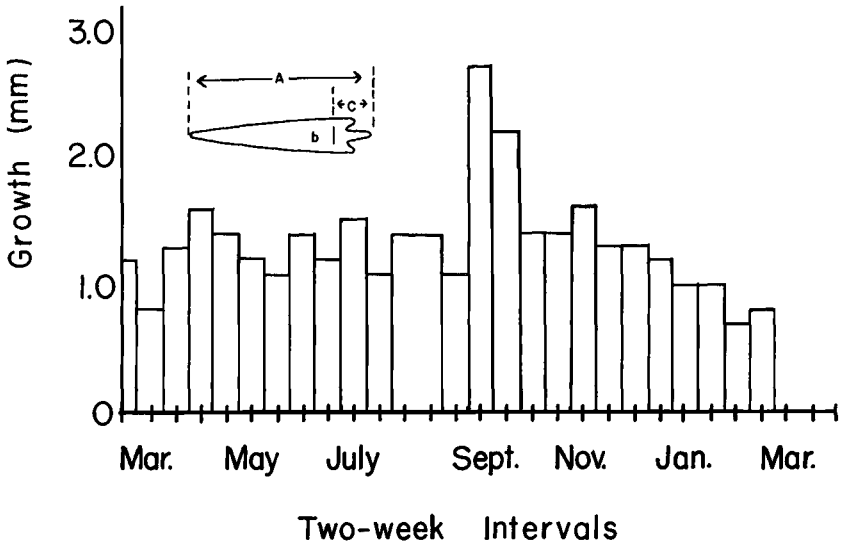

Figure 1. Growth of bills of adult male Starlings held in cages for a year. Each point is the average for 11 to 14 birds. Points for measurement of bills of Starlings (bird facing to the left): A, total length; B, mark for growth comparison; C, measurement for biweekly growth.

becomes black. Collections were begun too late to gather enough data for detailed analysis, but the information obtained will be discussed later.

Records of the change from yellow to black in the bills were also kept for 10 birds maintained in the laboratory while the rate of bill growth was being determined. The day length in the laboratory was gradually decreased from 15 to 9 hours, corresponding to the natural day lengths from July to October.

Length of bill.—Starlings collected near State College, Pennsylvania, between 4 July and 10 October 1961, were aged and sexed by the methods of Davis (1959). The length of each bill was measured to the nearest half millimeter (Figure 1, A). Then the average bill lengths with standard errors were determined for the various age and sex categories.

Growth of bill.—Starlings were kept at natural day-length in cages that measured six feet on all sides. The birds were fed *ad libitum* on a diet of mash-type dog food (manufactured by Eastern States Farmers' Exchange, Inc.; West Springfield, Massachusetts) and had water available. Following a two-week adjustment period, 14 adult males were weighed and the bills measured bi-weekly from 8 March 1963 to 15 March 1964. The bill of each bird was first marked ("B" in Figure 1) by a slender triangular file. This mark was renewed as often as necessary to maintain a narrow groove so that the distance from the upper bill attachment to the groove could be measured accurately. Initial and weekly measurements were made ("C" in Figure 1); the groove moved from the base toward the tip of the bill with growth.

RESULTS

Comparison of progression of yellow in bills by age and sex.—The combined data collected at Baltimore were averaged to show the progression of

TABLE 2

AVERAGE BILL COLOR IN ADULT STARLINGS PRIOR TO THE BREEDING SEASON AT BALTIMORE

Mid-point of collection dates[1]	*Males (657)*		*Females (471)*	
	Birds examined	*Average color class*[2]	*Birds examined*	*Average color class*[2]
October 5	38	0.00	4	0.00
October 24	26	0.04	10	0.10
November 12	39	0.67	21	0.29
November 23	21	0.86	28	0.44
December 7	72	1.08	50	0.45
December 23	99	1.55	92	0.41
January 10	37	2.03	40	0.66
January 22	111	2.29	49	0.98
February 9	88	2.49	66	1.18
February 20	41	2.64	45	1.04
March 8	62	2.61	37	1.78
March 21	23	2.61	30	1.77

[1] Average of 4 years (1954–1958).
[2] See Table 1.

the yellow pigment by using the mid-point of the collection dates (Tables 2 and 3). Tests of the coefficients of correlation for all age and sex categories show that these data were not different from a linear relationship (significant at the one per cent level). The equations that were obtained by using these data are given along with the 95 per cent confidence limits for "b" in Table 4. Adult male birds were significantly different (one per

TABLE 3

AVERAGE BILL COLOR IN SUBADULT STARLINGS PRIOR TO THE BREEDING SEASON AT BALTIMORE

Mid-point of collection dates[1]	*Males (669)*		*Females (595)*	
	Birds examined	*Average color class*[2]	*Birds examined*	*Average color class*[2]
October 5	9	0.11	4	0.00
October 24	15	0.00	5	0.00
November 12	48	0.10	31	0.09
November 23	28	0.11	37	0.05
December 7	52	0.29	60	0.03
December 23	132	0.46	95	0.17
January 10	60	1.23	47	0.32
January 22	51	1.37	46	0.70
February 9	97	1.96	100	1.03
February 20	54	2.35	63	1.43
March 8	102	2.43	66	1.93
March 21	21	2.48	41	1.90

[1] Average of 4 years (1954–1958).
[2] See Table 1.

TABLE 4

EQUATIONS FOR THE PROGRESSION OF YELLOW PIGMENT IN STARLING BILLS PRIOR TO THE BREEDING SEASON AT BALTIMORE, FROM 1954 TO 1958[1]

Age and sex	*Equation*	*95% Confidence limits for b*
Adult males	$C = .0180\ T$	$\pm .00290$
Adult females	$C = .0091\ T$	$\pm .00223$
Subadult males	$C = .0137\ T$	$\pm .00379$
Subadult females	$C = .0105\ T$	$\pm .00339$

[1] Equations were determined from data presented in Tables 2 and 3.

cent level) from the adult and subadult female birds in their rate of change to yellow bill color. Subadult males did not differ significantly from adult males, adult females, or subadult females. Adult females were not significantly different from subadult females in the rate of the progression of yellow.

For State College a small number of birds, collected in December and January, 1959–1960, showed that the bills were becoming yellow in January. The bills became yellow rapidly and by March had almost caught up with the Baltimore birds.

Disappearance of yellow in bills.—Eight adult and subadult birds in the first summer collections in State College (4–6 July 1961) had some black in their bills. In July, 24 adult and subadult birds were collected that had some yellow in their bills, while only five birds with completely black bills were taken. All except 3 of 29 birds collected in August had completely black bills. These findings indicate that the bills began to change to black some time in late June before a decrease in the length of day began.

Two adult males, three adult females, two subadult males, and three subadult females that were kept in the laboratory also began to show some color change before a reduction in day length actually occurred in the laboratory. The shortest time during which a complete change to black occurred in the laboratory was two weeks (one adult female and one subadult female). The longest time during which a complete change occurred was slightly over seven weeks (one adult male).

Comparison of bill lengths by age and sex.—The average bill lengths (Table 5) are very similar and showed no statistically significant differences, although males had longer bills than did females and adults had longer bills than did juveniles on the average.

Rate of bill growth.—The growth increments of the bills of males during intervals of two weeks are plotted on Figure 1. It is noteworthy that the rate was very even except in September just after the molt.

TABLE 5

AVERAGE BILL LENGTHS OF STARLINGS COLLECTED BETWEEN 4 JULY AND 10 OCTOBER 1961 AT STATE COLLEGE, PENNSYLVANIA

Age and sex	*Birds examined*	*Average length in mm*	*Standard error*	*Range in mm*
Adult males	32	26.98	.168	25.0–29.0
Adult females	30	26.25	.177	24.5–28.0
Subadult males	13	26.85	.191	25.5–28.0
Subadult females	4	26.25	—	25.0–28.0
Juvenile males	44	26.02	.188	22.0–28.0
Juvenile females	45	25.64	.141	23.0–27.5

DISCUSSION

The rate of the progression of yellow in Starling bills prior to the breeding season at Baltimore increased in the following order: adult females, subadult females, subadult males, and adult males. This sequence is probably attributable to the amount of androgen secreted by the gonads of the various age and sex categories of birds. For example, the rate of the progression of yellow pigment in subadult males is not as great as that in adult males. This result agrees with the findings of Bissonnette (1932), who pointed out that the testes of mature Starlings (having passed one season of sexual activity) react more quickly to photoperiodic changes that promote the production of hormones than do those of subadult birds (still in their first year of life). He further showed that subadult male birds react more quickly to decreasing amounts of daylight, as shown by the regression of the testes. With this fact in mind, one would expect the subadult birds to lose the yellow pigment faster after the breeding season is over. This situation was found to be true for the few birds that were kept in the laboratory. Among the females, the adults began the change to yellow earlier than did the subadults. The rate of change, although not significantly different between the two age groups, was numerically greater in subadult females and the two groups attained equivalent stages of yellow pigmentation by March.

The birds of the State College area differ considerably from the Baltimore birds in the time of year at which the yellow pigment first begins to appear. The birds at Baltimore begin to show yellow in the bills in October, while those at State College do not show the color until January. However, the birds at State College appear to catch up with the Baltimore birds by late March or early April. Baltimore is located at 39° 1′ N lat. and 76° 3′ W long., while State College is located at 40° 48′ N lat. and 77° 52′ W long. The difference in the time of color change at the two localities is probably due to differences in environmental conditions. However, there

exists the possibility that the birds belong to different "physiological races." Bullough (1942) reported such a difference between British and continental races of Starlings. For example, the males in Britain have completely yellow bills in February, while the males in Hungary and Holland do not have completely yellow bills until after mid-March. More data for State College birds would be necessary for a detailed comparison with Baltimore birds.

Although limited data are available concerning the disappearance of yellow in Starling bills after the breeding season, a few comments are in order on this aspect of the annual bill-color cycle. The bills of birds at State College begin to change to black near the end of June and have completed the change by the end of July. These data indicate that the change from yellow to black takes from four to six weeks. Hilton (1958) reported that birds involved in a second nesting maintain the all-yellow bill color during the second nesting period. The three birds with yellow tips on the bills that were collected in the middle of August were adults and may have been involved in a second nesting.

Macroscopic examination of bills when they were becoming black revealed that the black pigment progressed most rapidly from the base toward the tip. In addition, the pigment was deposited laterally and vertically in the bill and thereby produced a blackish bill with a yellow border. The yellow border was caused by the edge of the rhamphotheca, or cornified epithelium, that had not yet been replaced with epidermal cells containing melanin. Cross sections made at various places through the bill also showed that the black pigment was being deposited all along the growing portion of the bill.

The average length of the bill of a wild Starling is approximately 26 millimeters (Table 5) and the average growth rate of Starling bills in the laboratory was approximately 1 mm per 2 weeks or about 26 mm in 52 weeks. If the bills of wild birds grow at the same rate as those of the laboratory birds, then the color change in bills of the former could not result simply from growth of the bill.

Growth of the bills also could not account for the change from yellow to black. This change, for 10 Starlings that were kept in the laboratory, required only two to seven weeks, an insufficient length of time for the growth of the bill to account for the color change. Therefore, the amount of melanin produced by the melanophores must be greatly increased and the pigments must be distributed very quickly into the epidermal cells of the bill to produce the change to black in such a short time.

A few (10) birds of various ages and sexes were kept under decreasing day length (15–9 hours) from 18 July to 3 November 1961. Then the duration of light was suddenly increased to 15 hours until 5 January 1962.

The growth of the bill during decreasing days was about double that during the long days. Since other variables, such as temperature, were not controlled, this observation needs further testing.

SUMMARY

Average color classes were determined for the bills of Starlings (*Sturnus vulgaris*) collected at Baltimore, Maryland, in winter and spring between 1954 and 1958. The rates of progression of yellow pigment in the bills were expressed in the form of linear equations. The coefficients of correlation for color and time were found to be highly significant for adult and subadult birds in Baltimore. The slope of the bill-color line of adult males at Baltimore was found to be significantly greater than the slopes of the bill-color lines of adult females and subadult females. The complete change from a black to a yellow bill takes approximately six months for Baltimore birds.

Laboratory results obtained from adult and subadult birds of both sexes showed that a complete change from yellow to black can occur in as short a time as two weeks, while the longest time required for a complete change was slightly over seven weeks. Limited data for birds collected at State College indicate that the change from yellow to black takes from four to six weeks to be completed.

The change from black to yellow in the bills of wild Starlings cannot be accounted for by growth alone if they grow at the same rate (1 mm in 2 weeks) as those of Starlings kept in the laboratory. Also, the growth is too slow to account for the change from yellow to black. This color change must be attributed to an increased deposition of melanin in the epidermal cells of the bills.

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