

Supplemental Materials for:

Examination of Macaulay Library images to determine avian molt strategies: A case study on hummingbirds.

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Validation exercise to assess whether or not field ornithologists can accurately collect data on avian molt from images

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Table S1. Sample sizes for images and molt and plumage states, by month, for each of eight species of hummingbird that breed in the southwestern United States.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Rivoli's Hummingbird (<i>Eugenes fulgens</i>)													
<i>Number of Images</i>	201	151	474	527	542	425	605	569	226	171	170	185	4246
Juvenile Plumage				5	6	8	9	5	2	1			36
Preformative Molt	4	2			3	6	12	9	11	9	12	9	77
Formative Plumage	2	3	10	18	26	21	13	5				1	99
Second Prebasic Molt						3	6	9	3				21
Definitive Basic Plumage	13	9	21	34	42	27	34	24	5	3	12	14	238
Definitive Prebasic Molt							3	28	23	7	3		64
Total Individuals	19	14	31	57	77	65	77	80	44	20	27	24	535
Blue-throated Mountain-gem (<i>Lamphornis clemenciae</i>)													
<i>Number of Images</i>	317	123	108	222	309	231	343	446	111	105	137	91	2543
Juvenile Plumage					3	4	5	2					14
Preformative Molt					1	4	12	32	20	15	7	1	92
Formative Plumage	3	4	7	12	10	11	14	11			1	4	77
Second Prebasic Molt							1	19	4				24
Definitive Basic Plumage	8	9	7	19	21	16	29	37	14	3	9	4	176
Definitive Prebasic Molt								14	16	5	1		36
Total Individuals	11	13	14	31	35	35	61	115	54	23	18	9	419
Lucifer Hummingbird (<i>Calothrax lucifer</i>)													
<i>Number of Images</i>	12	4	124	517	531	333	528	845	438	132	20	10	3494
Juvenile Plumage				14	19	19	25	17	9	4			107
Preformative Molt						2	10	57	57	24	1		151
Second Prebasic Molt	3		1						1		2	3	10
Definitive Basic Plumage		1	20	82	102	70	92	117	39	7	1		531
Definitive Prebasic Molt	4						3	58	55	7	4	1	132
Total Individuals	7	1	21	96	121	91	130	249	161	42	8	4	931

Table S1 (cont.). Sample sizes for images and molt and plumage states, by month, for each of eight species of hummingbird that breed in the southwestern United States.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Broad-billed Hummingbird (<i>Cyanthus latirostris</i>)													
<i>Number of Images</i>	631	424	1160	1097	1028	642	1184	959	482	473	440	322	8842
Juvenile Plumage			2	8	16	20	20	11	2				79
Preformative Molt	3	3	0	0	2	10	117	130	38	27	11	7	348
Formative Plumage	24	13	39	69	79	32	12	1			3	11	283
Second Prebasic Molt					1	27	124	99	5	1			257
Definitive Basic Plumage	36	39	117	150	137	71	182	60	37	34	36	20	919
Definitive Prebasic Molt						10	184	285	44	4			527
Total Individuals	63	55	158	227	235	170	639	586	126	66	50	38	2413
White-eared Hummingbird (<i>Basilinna leucotis</i>)													
<i>Number of Images</i>	40	44	33	20	126	236	259	273	40	16	17	33	1137
Juvenile Plumage			4	1	1	4	1	3	1				15
Preformative Molt					2	8	14	14	4	0			42
Formative/Basic Plumage	19	17	12	9	22	25	12	18	9	6	9	12	170
Second/Definitive Prebasic Molt						3	23	20	6	1			53
Total Individuals	19	17	16	10	25	40	50	55	20	7	9	12	280
Violet-crowned Hummingbird (<i>Leucolia violiceps</i>)													
<i>Number of Images</i>	198	171	354	336	275	128	522	418	126	68	71	170	2837
Juvenile Plumage					1	4	8	5	0	0	0	0	18
Preformative Molt	2					11	35	36	24	12	4	2	126
Formative Plumage	6	8	24	20	3				3	7	6	11	88
Second Prebasic Molt				18	26	7							51
Definitive Basic Plumage	7	10	18	27	19	37	67	48	15	6	6	2	262
Definitive Prebasic Molt					3	6	18	21	6	2			56
Total Individuals	15	18	42	65	52	65	128	110	48	27	16	15	601

Table S1 (cont.). Sample sizes for images and molt and plumage states, by month, for each of eight species of hummingbird that breed in the southwestern United States.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Berylline Hummingbird (<i>Saucerottia beryllina</i>)													
<i>Number of Images</i>	57	43	59	79	339	349	134	304	108	33	48	54	1607
Juvenile Plumage						1		4	1		1		7
Preformative Molt	2							2	3	6	8	9	30
Formative Plumage	5	2	1								1	10	19
Second Prebasic Molt	3	3	10	5	1	1						1	24
Definitive Basic Plumage	5	6	11	13	23	31	37	35	19	14	8	4	206
Definitive Prebasic Molt	7	1	1				1	2	2	5	15	18	52
Total Individuals	22	12	23	18	24	33	38	43	25	25	33	42	338
Buff-bellied Hummingbird (<i>Amazilia yucatanensis</i>)													
<i>Number of Images</i>	563	425	305	365	120	47	42	33	113	142	459	261	2875
Juvenile Plumage		3	7	5			1						16
Preformative Molt		2	4	4	7	4	7	5	8	12	18	3	74
Formative Plumage	40	23	16	20	4		1	2	3	7	23	30	169
Second Prebasic Molt	6	8	2		1						2	3	22
Definitive Basic Plumage	77	81	62	79	28	14	12	8	14	12	58	48	493
Definitive Prebasic Molt	0	1	1	2			1	1	10	13	19	6	54
Total Individuals	123	118	92	110	40	18	22	16	35	44	120	90	828
Total Individuals (all species)	279	248	397	614	609	517	1145	1254	513	254	281	234	6345

Table S2. Earliest date, latest date, links to voucher images, and days of duration recorded for each plumage and molt state for each of eight species of hummingbird that breed in the southwestern United States.

	Earliest Date	Image Link	Latest Date	Image Link	No. days ¹
Rivoli's Hummingbird (<i>Eugenes fulgens</i>)					
Juvenile Plumage	5 Apr (2017)	ML53539161	6 Oct (2017)	ML71217491	184
Preformative Molt	19 May (2009)	ML35507671	25 Feb (2018)	ML87527351	282
Formative Plumage	27 Dec (2018)	ML131888891	27 Aug (2017)	ML67175761	130
Second Prebasic Molt	8 Jun (2020)	ML242091451	15 Sep (2017)	ML69429691	99
Definitive Basic Plumage	7 Sep (2018)	ML115560961	1 Sep (2018)	ML114745281	359
Definitive Prebasic Molt	16 Jul (2020)	ML250033061	22 Nov (2019)	ML189631681	129
Blue-throated Mountain-gem (<i>Lamphornis clemenciae</i>)²					
Juvenile Plumage	12 May (2018)	ML104413711	23 Aug (2019)	ML174516651	103
Preformative Molt	31 May (2008)	ML116833491	31 Dec (2018)	ML132225371	214
Formative Plumage	23 Nov (2018)	ML125145541	26 Aug (2016)	S31263149	276
Second Prebasic Molt	23 Jul (2016)	ML91903061	24 Sep (2017)	ML70364721	63
Definitive Basic Plumage	30 Sep (2017)	ML70410371	18 Sep (2014)	ML61572141	353
Definitive Prebasic Molt	2 Aug (2019)	ML177245281	4 Nov (2018)	ML125171011	94
Lucifer Hummingbird (<i>Calothrax lucifer</i>)³					
Juvenile Plumage	14 Apr (2016)	ML27082041	14 Oct (2016)	ML37413671	183
Preformative Molt	5 Jun (2020)	S70103132	4 Nov (2017)	ML74135881	152
Second Prebasic Molt	8 Sep (2017)	ML68546921	2 Mar (2018)	ML88246211	176
Definitive Basic Plumage	28 Feb (2019)	ML143090201	15 Nov (2015)	ML21063081	260
Definitive Prebasic Molt	3 Jul (2020)	ML247351211	20 Jan (2020)	ML200761501	201
Broad-billed Hummingbird (<i>Cyanthus latirostris</i>)					
Juvenile Plumage	16 Mar (2020)	ML215925901	6 Sep (2016)	ML34443551	143
Preformative Molt	26 Jun (2020)	ML245827291	19 Feb (2018)	ML86692301	238
Formative Plumage	14 Nov (2016)	ML39926711	1 Aug (2019)	ML197319181	260
Second Prebasic Molt	21 May (2018)	ML101361191	2 Oct (2018)	ML120044251	134
Definitive Basic Plumage	27 Jul (2020)	ML252081611	24 Aug (2005)	ML87864221	393
Definitive Prebasic Molt	7 Jun (2019)	ML167008081	10 Oct (2019)	ML183630481	156
White-eared Hummingbird (<i>Basilinna leucotis</i>)⁴					
Juvenile Plumage	9 Mar (2020)	ML220372891	11 Sep (2019)	S59696591	186
Preformative Molt	28 May (2020)	ML239528951	24 Sep (2015)	S30924176	148
Formative/Basic Plumage	10 Aug (2008)	ML136971191	19 Aug (2019)	ML173276031	374
Second/Definitive Prebasic Molt	3 Jun (2013)	ML222523661	6 Oct (2019)	ML185831481	125
Violet-crowned Hummingbird (<i>Leucolia violiceps</i>)					
Juvenile Plumage	30 May (2014)	ML34273361	16 Aug (2018)	ML112325371	78
Preformative Molt	20 Jun (2020)	ML244744561	24 Jan (2020)	ML202657101	218
Formative Plumage	11 Sep (2019)	ML213615071	29 May (2009)	ML111468491	260
Second Prebasic Molt	9 Apr (2009)	ML191090781	13 Jun (2020)	ML243892441	65
Definitive Basic Plumage	11 June (2018)	ML131533621	17 Sep (2016)	ML62598551	267
Definitive Prebasic Molt	3 May (2010)	ML245135201	28 Oct (2019)	ML185533471	178

Table S2 (cont.). Earliest date, latest date, links to voucher images, and days of duration recorded for each plumage and molt state for each of eight species of hummingbird that breed in the southwestern United States.

	Earliest Date	Image Link	Latest Date	Image Link	No. days ¹
Berylline Hummingbird (<i>Saucerottia beryllina</i>)					
Juvenile Plumage	27 Jun (2020)	ML246032741	18 Nov (2018)	ML124156711	144
Preformative Molt	18 Aug (2019)	ML173051291	21 Jan (2018)	ML82872751	156
Formative Plumage	20 Nov (2017)	ML75733781	16 Mar (2010)	ML24493361	116
Second Prebasic Molt	12 Dec (2019)	ML192834001	9 Jun (2020)	ML242471461	186
Definitive Basic Plumage	22 Jan (2020)	ML210693961	22 Dec (2015)	ML22259701	334
Definitive Prebasic Molt	10 Jul (2017)	ML63020951	10 Mar (2015)	ML46645931	243
Buff-bellied Hummingbird (<i>Amazilia yucatanensis</i>)					
Juvenile Plumage	2 Feb (2002)	ML23055171	14 Jul (2010)	ML 126355861	162
Preformative Molt	11 Feb (2017)	ML48095981	17 Dec (2017)	ML78493091	309
Formative Plumage	20 Jul (2016)	S30779253	19 May (2020)	S69336911	333
Second Prebasic Molt	4 Nov (2016)	ML39289491	11 May (2017)	ML57657391	188
Definitive Basic Plumage	10 Sep (2006)	ML163757271	26 Nov (2003)	ML34434691	442
Definitive Prebasic Molt	29 Jul (2018)	ML109577131	26 Apr (2016)	ML 44139031	271

¹ Days duration from earliest to latest dates in table (non-leap-year calendar). Note that values can be > year for conditions showing substantial individual variation in timing (e.g., for definitive basic plumage).

² Post-fledging male Blue-throated Mountain-gems with blue iridescent feathers in the throat were categorized as in formative rather juvenile plumage (see Supplemental Figure S9).

³ No line is presented for formative Lucifer Hummingbirds due to lack of sample sizes.

⁴ No lines are presented for White-eared Hummingbirds for formative plumage or undergoing the second prebasic molt as these states can not be identified in photographs (see text and Supplemental Figure S5).

Figures S1-S8. Images of southwestern hummingbirds exemplifying different molts and plumages and useful for age determination. Species are: Figure S1 - Rivoli's Hummingbird (*Eugenes fulgens*), Figure S2 - Blue-throated Mountain-gem (*Lamphornis clemenciae*), Figure S3 - Lucifer Hummingbird (*Calothrax lucifer*), Figure S4 - Broad-billed Hummingbird (*Cynanthus latirostris*), Figure S5 - White-eared Hummingbird (*Basilinna leucotis*), Figure S6 - Violet-crowned Hummingbird (*Leucolia violiceps*), Figure S7 - Berylline Hummingbird (*Saucerottia beryllina*), and Figure S8 - Buff-bellied Hummingbird (*Amazilia yucatanensis*).

For most species six images are shown, exemplifying juvenile plumage, preformative molt, formative plumage, second prebasic molt, definitive basic plumage, and definitive prebasic molt. Broad-billed Hummingbird shows more variation to the extent of the preformative molt, hence 12 images are shown in Figure S4. In White-eared Hummingbird plumages cannot be identified after the complete preformative molt so additional images of birds undergoing this molt are shown in Figure S5. Dates of images shown are typical of the timing for each of these molts and plumages.

Brief notes on age-determination criteria are noted under each image. Males are shown for the most part; however criteria related to wing feathers apply to ageing females as well. New criteria emphasized include differences between juvenile and basic wing feathers, molt limits among greater coverts, contrasts between newer secondaries and older primaries (s1-p1 contrast), and in some cases molt clines among primaries. Juvenile outer primaries and secondaries tend to be much browner and more worn than replaced basic primaries of the same age, which are duskier and often more lustrous. Many hummingbirds that undergo partial molts replace at least some upperwing lesser coverts and retain at least some greater coverts, resulting in molt limits within these tracts that are useful for ageing; coverts generally appear to be replaced in a distal-caudal direction, as in passerines (see Figure 133 in Pyle 1997). In birds undergoing protracted molt, an s1-p1 contrast results from the secondaries being replaced well after the inner primaries, in hummingbirds not until p6-p7 are being replaced, by which time inner primaries can be 2-3 months old and show more wear. Likewise, molt clines can also be visible among primaries after protracted molts, with p9, the last feather replaced in hummingbirds, being fresher and appearing slightly darker than both p8 and p10. Birds with juvenile remiges, in contrast, have uniform feathers which were all grown at the same time and show no contrasts or clines due to age; if anything, secondaries are paler and browner than primaries after several months post-fledging due to increased solar exposure. These differences can help distinguish formative from definitive basic plumages in hummingbirds, especially in females, which often lack age-related differences in appearance of body feathering (cf. Supplemental Figure S9).

Links to Macaulay Library specimen pages (ML followed by 8 or 9 numerals) for each image are provided and can be used to view enlarged version of each image, along with the photographer and more detail on location and other aspects of the record.

Figure S1. Images exemplifying molts and plumages in Rivoli's Hummingbird.



Juvenile female. Note fresh scaly plumage (juvenile males have darker scalloping). 22 May 2015, Arizona, [ML193444241](#).



Male undergoing second prebasic molt. Note unmolted juvenile p9-p10 and s3-s4; p8, s2, and s5 are growing. 16 Sep 2017, Arizona, [ML69483461](#).



Male undergoing preformative molt. Note incoming gorget feathers, fresh remiges and duller greater coverts. 4 Aug 2020, Arizona, [ML171128561](#).



Definitive basic male. Note contrast between newer secondaries and older primaries. 8 Mar 2018, Arizona, [ML90525171](#).



Formative male. Note retained brown juvenile primaries and secondaries. See also Figure 2. 19 May 2013, Arizona, [ML42934871](#).



Male undergoing definitive prebasic molt. Note unmolted remiges are duskier than retained juvenile feathers during second prebasic molt. 22 Aug 2015, Arizona, [ML128951341](#).

Figure S2. Images exemplifying molts and plumages in Blue-throated Mountain-gem.



Juvenile. None of 14 juveniles examined showed blue in throat, indicating these may be formative feathers. 1 Aug 2016, Arizona, [ML33117161](#).



Male commencing second prebasic molt, with p1-3 growing. Note incomplete gorget and worn juvenile outer primaries, secondaries, and remaining greater covert. 13 Aug 2019, Arizona, [ML172907241](#).



Male undergoing preformative molt. Note incomplete gorget, fresh wings, and duller greater coverts. 2 Sep 2017, Arizona, [ML71224011](#).



Definitive basic male. Note full gorget and lustrous dark remiges. 4 Jun 2016, [ML29989261](#).



Formative male. Note incomplete gorget, molt limit in wing coverts, and retained brown juvenile primaries and secondaries. See also Figure 2. 14 Jul 2018, Arizona, [ML195618151](#).



Male undergoing definitive prebasic molt. Note relatively dark and unworn outer primaries and secondaries. 9 Aug 2018, Arizona, [ML116501471](#).

Figure S3. Images exemplifying molts and plumages in Lucifer Hummingbird.



Juvenile. Note fresh scaly plumage and buff underparts. 7 Oct 2015, Arizona, [ML20623111](#).



Female undergoing second prebasic molt. Note unmolted, worn brown juvenile p9-p10 and s4; p8 is growing. 2 Mar 2018, Distrito Federal, Mexico, [ML88246211](#).



Male undergoing preformative molt. Note uniformly brownish remiges, mixed juvenile and formative (brighter green) back feathers, and formative gorget feathers. Beware occasional definitive basic females can also show purple gorget feathers. 13 Aug 2016, Texas, [ML36340281](#).



Definitive basic male. Note full gorget, contrast between newer secondaries and older primaries, and molt cline within primaries, p9 appearing newest, a sign of a complete prebasic molt. 26 Aug 2009, Arizona, [ML174774571](#).



Male undergoing preformative molt or in formative plumage. Crown feathers appear primarily formative, along with a number of gorget feathers. See also Figure 2. 3 Nov 2015, Texas, [ML20744131](#).



Male undergoing definitive prebasic molt. Note full gorget and dusky basic primaries and secondaries. 7 Sep 2019, Texas, [ML176897521](#).

Figure S4. Images exemplifying molts and plumages in Broad-billed Hummingbird.



Juvenile male. Note fresh scaly plumage. Males can have a blue wash to juvenile throat feathers but these are not structured like formative gorget feathers. 12 May 2016, Arizona, [ML35544921](#).



Male undergoing incomplete or complete preformative molt, with p1-p6 and central rectrices being replaced along with body feathering. 27 Aug 2019, Arizona, [ML174429551](#).



Male commencing preformative molt. Note mixed juvenile and formative upperpart feathers, incoming gorget feathers on throat, and fresh remiges. 30 Jun 2020, Arizona, [ML246780721](#).



Male undergoing partial preformative molt, replacing body feathers but retaining juvenile flight feathers. 17 Oct 2019, Colorado, [ML182857441](#).



Male undergoing incomplete or complete preformative molt, with p1-p4 and central rectrices being replaced along with body feathering. See also Figure 3. 15 Aug 2019, Arizona, [ML172702421](#).

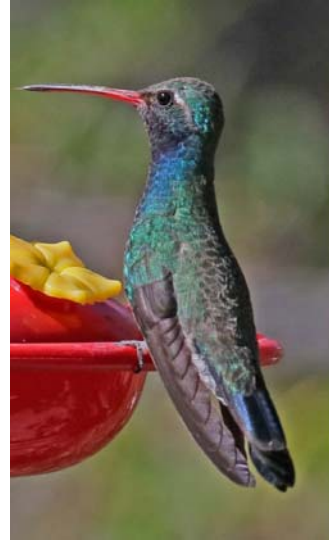


Formative male following partial preformative molt. Note retained juvenile flight feathers and molt limits among upperwing coverts. See also Figure 2. 22 Apr 2014, Arizona, [ML226047701](#).

Figure S4 (cont.). Molts and plumages in Broad-billed Hummingbird.



Formative male. Note retained juvenile remiges but replaced formative upperwing coverts. 21 Jun 2020, Arizona, [ML246664461](#).



Definitive basic or formative male. Note uniform basic upperwing coverts, darker secondaries than inner primaries, and darker p9 as part of molt cline. Formative males following complete molts may be indistinguishable from definitive basic males. 24 Mar 2019, Arizona, [ML148402901](#).



Formative male following complete preformative molt. All flight feathers have been replaced but body feathering appears predefinitive. 6 May 2020, Arizona, [ML233606291](#).



Definitive basic or formative male. Note uniform secondary coverts and darker secondaries than primaries. 23 May 2016, Arizona, [ML126747531](#).



Male undergoing second prebasic molt. Note unmolted, worn and brown, juvenile primaries, secondaries, and central greater covert. 10 Jul 2019, Arizona, [ML168722681](#).



Male undergoing definitive or second prebasic molt. Note non-juvenile feathers; it is possible that body feathering is predefinitive indicating a second prebasic molt. 9 Aug 2019, Arizona, [ML171934321](#).

Figure S5. Images exemplifying molts and plumages in White-eared Hummingbird.



Juvenile. Note fresh scaly plumage and dull bill. 21 Aug 2019, Arizona, [ML173592171](#).



Male completing preformative molt. The juvenile p9 and s4 remain while body-feather molt into a definitive male appearance has almost completed. 2 Aug 2009, Arizona, [ML112506621](#).



Male undergoing preformative molt. Note concurrence of body feather and primary molt (p1-p3 dropped) as part of complete molt. 13 Jun 2019, Arizona, [ML168126461](#).



Definitive basic or formative male. Formative males reach full definitive appearance such as this following complete preformative molts and cannot be distinguished from definitive basic males. 13 Jan 2016, Jalisco, [ML31576911](#).



Male undergoing preformative molt. P1-p5 are molting at the same time that body feathering is molting. 9 Aug 2020, Arizona, [ML255139331](#).



Male undergoing second or definitive prebasic molt. P6-p7 are dropped. 30 Jul 2006, Arizona, [ML223535491](#).

Figure S6. Images exemplifying molts and plumages in Violet-crowned Hummingbird.



Juvenile. Note fresh scaly plumage, dull bill, and lack of purple iridescent feathers in crown. 5 Jul 2020, Arizona, [ML247770321](#).



Individual completing second prebasic molt. Note unmolted juvenile p9-p10 and s3-s5; p8 is growing. Molt timing matches that of the second prebasic molt as the definitive prebasic molt only commences in May. 9 May 2011, Arizona, [ML206043871](#).



Individual undergoing preformative molt. Note fresh wings and brighter formative feathers in crown and among lesser coverts. Inner primaries can occasionally be replaced during this molt (Figure 3). 18 Nov 2017, Arizona, [ML75461301](#).



Definitive basic plumage. Note definitive appearance of body plumage, lack of molt limits in secondary coverts, and dusky remiges. 7 Jan 2020, Arizona, [ML199909891](#).



Formative plumage. Note retained brownish juvenile primaries and secondaries and molt limits in secondary coverts; crown is predefinitive in appearance. See also Figure 2. 27 Jan 2019, Arizona, [ML137511331](#).



Male undergoing definitive prebasic molt. Note retained unmolted remiges are duskier than retained juvenile feathers. 10 Aug 2018, Arizona, [ML111503391](#).

Figure S7. Images exemplifying molts and plumages in Berylline Hummingbird.



Juvenile. Note fresh scaly plumage, lacking glittering green. 27 Jun 2020, Distrito Federal, Mexico, [ML246032741](#).



Individual undergoing second prebasic molt. Note unmolted juvenile p8-p10 and s2-s5; p7, s1, and s6 are growing. 5 May 2020, Arizona, [ML233601741](#).



Individual undergoing preformative molt. Note mixed body feathering, brown remiges and greater coverts, and dull bill. 13 Aug 2019, Arizona, [ML172361791](#).



Definitive basic plumage. Note lustrous remiges and lack of molt limits among secondary coverts. 12 Aug 2009, Distrito Federal, Mexico, [ML46645931](#).



Formative plumage. Note mixed juvenile and formative body feathers and retained brown juvenile primaries and secondaries. See also Figure 2. 20 Jan 2018, Jalisco, Mexico, [ML83111211](#).



Individual undergoing definitive prebasic molt. Note unmolted outer primaries and secondaries are less worn than retained juvenile feathers. 10 Mar 2005, Distrito Federal, Mexico, [ML46645931](#).

Figure S8. Images exemplifying molts and plumages in Buff-bellied Hummingbird.



Juvenile. Note fresh scaly upperparts and lack of glittering feathers. 9 Mar 2017, Texas, [ML50659971](#).



Individual undergoing second prebasic molt. Note unmolted juvenile p7-p10, outer rectrices, and most secondaries. 11 May 2017, Texas, [ML57657391](#).



Individual undergoing preformative molt. Note fresh wings, brown juvenile remiges, and duller greater coverts. 8 Jan 2019, Texas, [ML134258441](#).



Definitive basic plumage. Note definitive body-feather appearance, lustrous dark remiges and basic rectrices. 26 Nov 2013, Louisiana, [ML128861271](#).



Formative plumage. Note retained brown juvenile primaries and secondaries and dull greater coverts. See also Figure 2. 18 Apr 2017, Texas, [ML58643721](#).

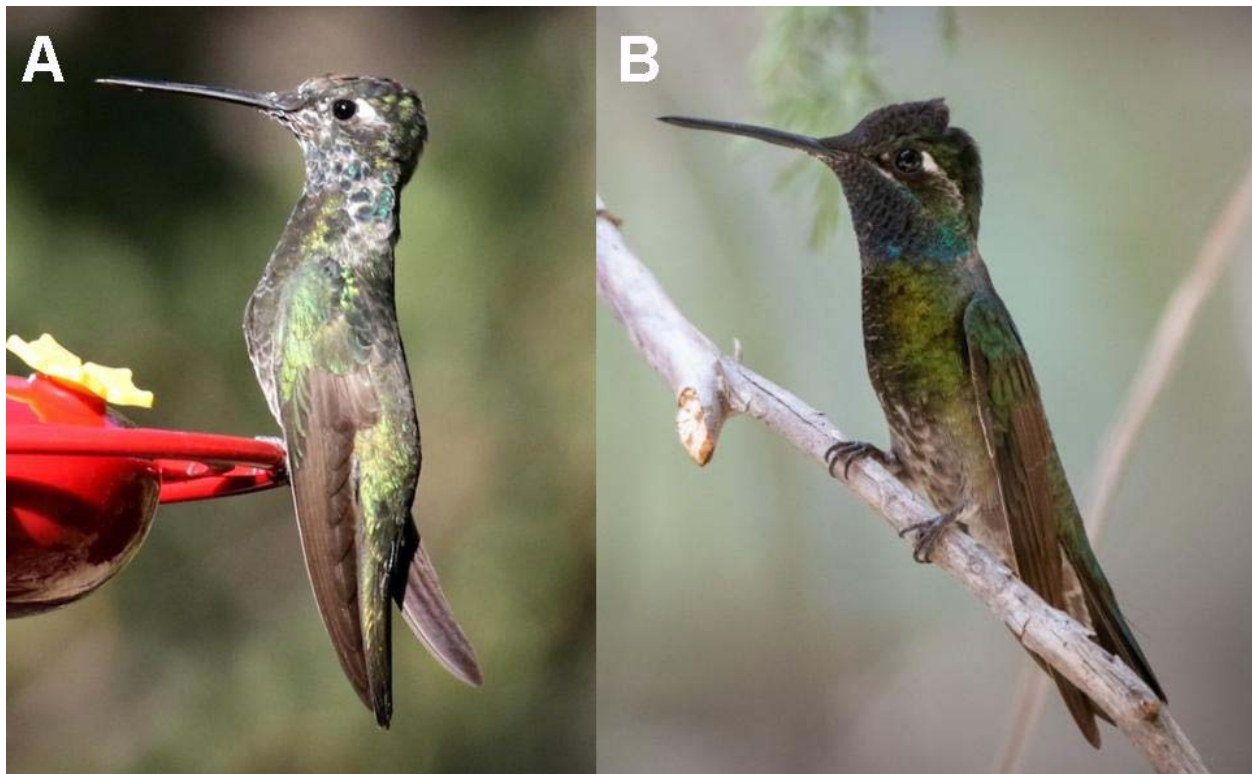


Individual undergoing definitive prebasic molt. Note definitive body-feather appearance, broad dusky unmolted outer primaries. 10 Nov 2018, Louisiana, [ML122879681](#).

Figures S9. Images of southwestern hummingbirds exemplifying ranges in variation of formative male plumages.

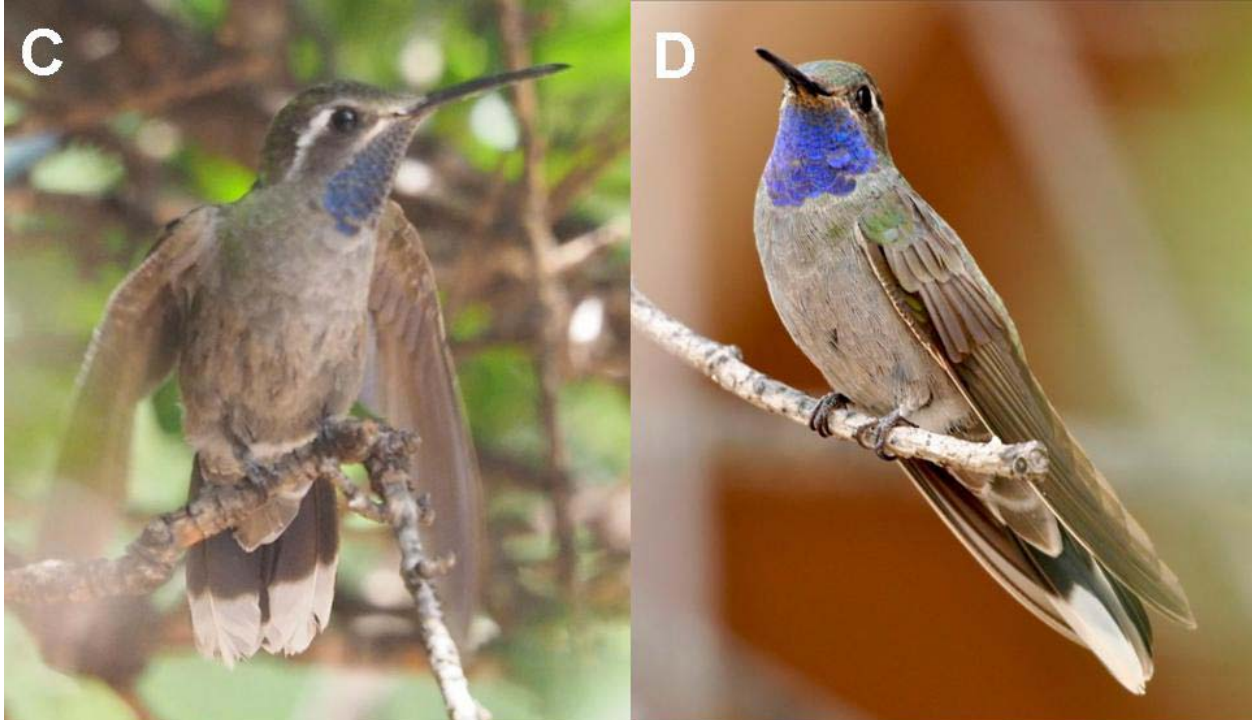
Assessing the degree of definitive-like appearance in formative male hummingbirds can be challenging due to the effects of light and angle on iridescent gorget and other feathers. The following images were chosen as those that appear to depict the full extent of definitive-like appearance on each individual. When eBird checklist links are provided it indicates that several images of the same bird should be examined to fully appreciate extent of definitive-like appearance. Images represent worn formative birds during the period following the period of preformative molt but before commencement of the second prebasic molt. Five species are shown; not enough good images representing variation in formative Lucifer (*Calothrax lucifer*) and Berylline (*Saucerottia beryllina*) hummingbirds were available and for White-eared Hummingbird (*Basilinna leucotis*), formative plumage resembles definitive plumage in appearance and cannot be identified in images.

Formative plumage is indicated in these five species by retained juvenile primaries, worn brown secondaries, and molt limits within the upperwing coverts. Links to Macaulay Library specimen pages (ML followed by 8 or 9 numerals) or eBird Checklists (S followed by 7 or 8 numerals) are provided and can be used to view each enlarged versions of each image, the photographer, and more detail on location and other aspects of the record. For four of these five species (all but Broad-billed Hummingbird), formative male plumage typically does achieve full definitive appearance.

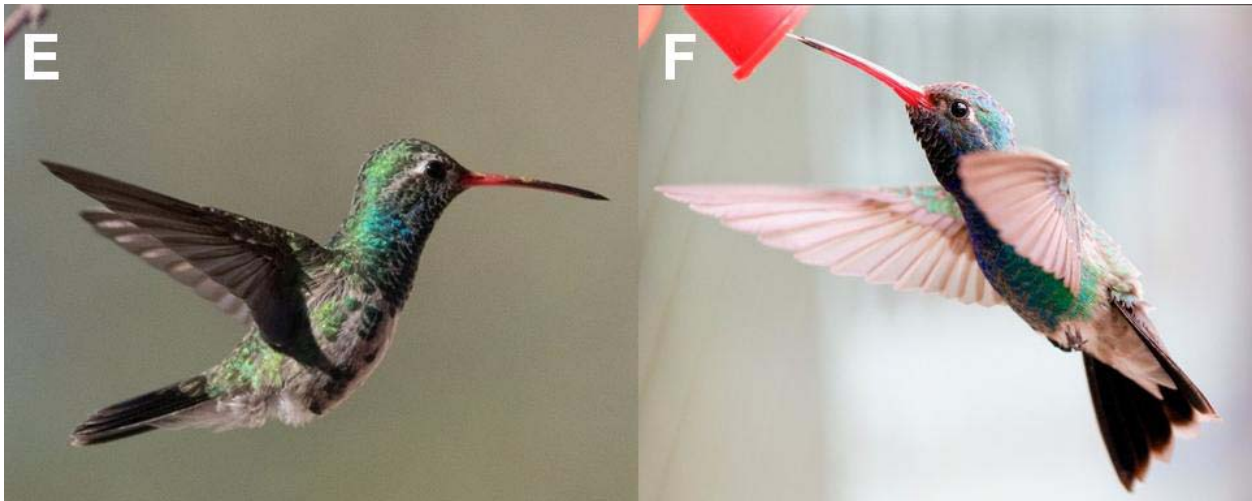


Rivoli's Hummingbird (*Eugenes fulgens*). Minimal (A) and typical (B) development of definitive-like appearance in formative male plumage. Some definitive basic males can show brownish feathers in the belly as in B (though usually less); study needed whether or not this

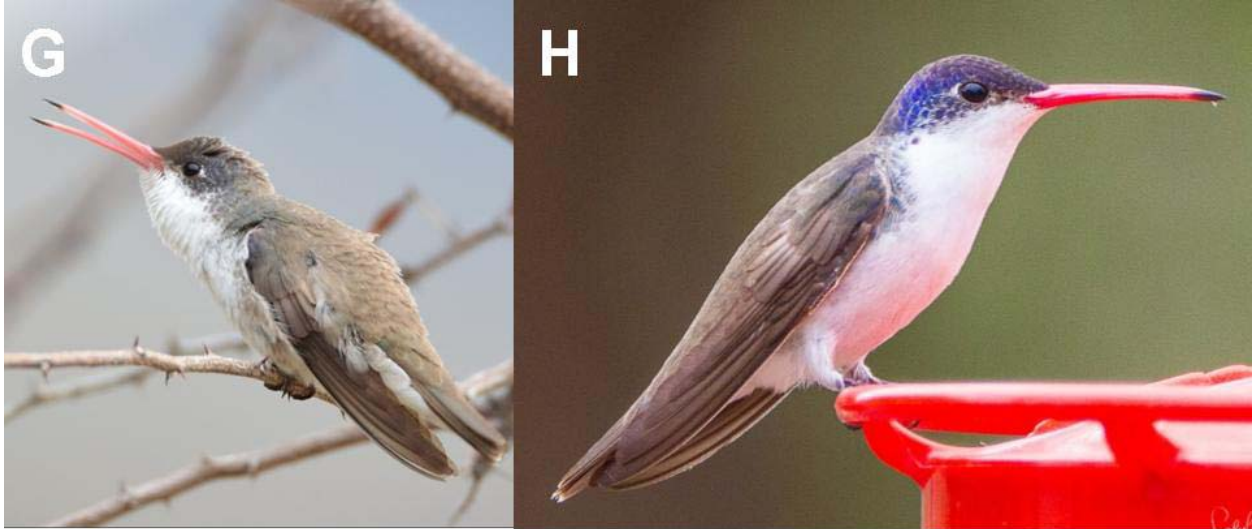
may be typical of second basic plumage. **A:** 23 May 2016, Arizona ([ML29438681](#)). **B:** 14 Jun 2020, Arizona ([ML243435551](#)).



Blue-throated Mountain-gem (*Lamphornis clemenciae*). Minimal (C) and typical (D) development of definitive-like appearance in formative male plumage. None of 14 juveniles including nestlings (cf. [S38554125](#)) showed iridescent blue feathers, and no other hummingbirds show iridescent juvenile feathers, suggesting that these are formative but developed quickly during or following fledging (contra Pyle and Howell 2000). C: 10 Aug 2018, Arizona ([S47766378](#)). D: 14 Jul 2018, Arizona ([S53611145](#)).



Broad-billed Hummingbird (*Cyanthus latirostris*). Minimal (E) and typical (F) development of definitive-like appearance in formative male plumage. The preformative molt and development of definitive-like appearance can vary from partial to complete (see also Figures 2, 3, and S4). E: 3 Apr 2020, Arizona ([S66679154](#)). F: 16 May 2019, Arizona ([ML160635031](#)).



Violet-crowned Hummingbird (*Leucolia violiceps*). Typical (**G**) and maximum (**H**) development of definitive-like appearance in formative male plumage. See the eBird checklist for variation among photographs for the bird in **G**. **G**: 24 Mar 2018, Arizona ([S43931142](#)). **H**: 10 Mar 2018, Arizona ([S43537351](#)).



Buff-bellied Hummingbird (*Amazilia yucatanensis*). Minimum (**I**) and maximum (**J**) development of definitive-like appearance in formative male plumage. Formative plumage is found more widely throughout the year in Buff-bellied Hummingbirds than in the other southwestern species (Table S2). **I**: 19 Apr 2019, Texas ([ML154689091](#)). **H**: 28 Mar 2017, Texas ([ML52660381](#)).

Appendix 1. Validation exercise undertaken by 17 participants including the author on 11 hummingbirds to assess whether or not field ornithologists can accurately collect data on avian molt from images. (A) Participants were asked to rank their previous experience with banding and field observation as Low, Medium, or High, to fill out all cells for age, molt status, and condition of each primary (p1 to p10), and to estimate how many minutes it took to complete each line of data. "Correct" answers are given, those indicating the best possible conclusions by the author after evaluating all results. (B) Indicates the proportion of "correct" answers for each cell recorded by the 17 participants.

Evaluation

Participants correctly aged the 11 hummingbirds a mean 83% of the time, reached a correct conclusion on molt status 93% of the time, and provided correct answers for the condition of each primary from 83 to 91% of the time. For individual primary cells, correct answers ranged from 6% and 18%, up to 100% for most, with a mean of 87.2% (with the caveat that most primaries were easily scored). The mean time it took to complete each line was 3.7 minutes. The mean proportion of correct answers for the 132 cells was 87.5% (again with the above caveat). For the 17 observers this ranged from 80.3% to 95.4%. Among participants with Low, Medium, and High experience levels, correct answers were provided for 83.1% ($n=3$), 87.1% ($n=3$), and 88.9% ($n=11$) for banding experience and 87.6% ($n=3$), 86.6% ($n=8$), and 88.9% ($n=6$) for field experience, respectively.

There were no real patterns among errors on age determination, although most participants aged males in formative plumage and adult males in full definitive appearance correctly. For the three hummingbirds that were not in active molt (images 2, 6, and 10), correct answers were given by all 17 participants for molt status and for each primary condition. Some participants did not notice that the inner primaries had dropped for the birds in images 5, 7, and 11 and considered molt "inactive" for these. Several of the discrepancies for primary condition of individual feathers involved whether a primary had completed growth (score N) or not (score G). In image 9, for example, the author and others scored p6 as "N" but careful comparison with spacing of these primaries on other hummingbirds indicates that it is not quite fully grown, and should be scored "G," as some participants did. This is not a significant error, or one that would matter in molt analyses. For the White-eared Hummingbird in image 3, participants had trouble determining if the erupting pin feather was p5 or was p4, with p5 being missing. This resulted in low proportions of correct answers for the inner primaries, whether or not the pin feather was considered p4 or p5.

The biggest error rates occurred with the outer four primaries in images 1 and 4. Many participants did not take into account the sequence of outer primary replacement in hummingbirds, p8-p10-p9, and thus mistook the single remaining old primary as p10 rather than p9. In image 4, for example, p8 is "G," p9 is "O," and p10 is X. Only two participants recorded all three of these primaries correctly. In addition, many coded p7 on this bird as "N" but it is not yet completed growth and should be coded "G." In image 1 there are two old primaries left but one of these is the old primary from the other wing and difficulty in counting the inner primaries resulted in each of p7 and p8 being variously scored as N, G, or X. After Evaluation of inner primary spacing in other hummingbirds indicates that p2 is there but hard to see, and so the correct answer is P7 = N, p8 = G (not quite fully grown), p9 = O, and p10 = X. Overall, however, participants performed well in evaluating images based on the methodology and criteria presented herein.

A) Final Determinations for Hummingbird Exercise

Age: Enter FY (first year, or HY/SY, through the 1st molt of primaries) or AD (adult, AHY/ASY, older)

Molt Status: Enter "active" if primaries are in active molt or "inactive" if not.

p1 to p10: Fill out only if you entered "active" for molt status. Enter N = New, X = not visible due to molt, G = visible and growing, O = Old

Minutes: Enter the number of minutes it took you to come to your conclusion, to the nearest 5 minutes.

IMAGE	SPECIES	ML LINK	AGE	MOLT	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	MINUTES
1	RIHU	ML112128831	FY	active	N	N	N	N	N	N	N	G	O	X	
2	VCHU	ML161385411	AD	inactive											
3	WEHU	ML255139331	FY	active	N	N	G	G	X	O	O	O	O	O	
4	BEHU	ML238319331	FY	active	N	N	N	N	N	N	G	G	O	X	
5	BBIH	ML251781011	AD	active	N	N	X	O	O	O	O	O	O	O	
6	BTMG	ML53554351	FY	inactive											
7	BBIH	ML66989701	FY	active	X	X	X	O	O	O	O	O	O	O	
8	RIHU	ML181183661	AD	active	N	N	N	N	N	X	O	O	O	O	
9	BEHU	ML212588541	FY	active	N	N	N	N	N	G	X	O	O	O	
10	BBEH	ML56665951	FY	inactive											
11	VCHU	ML54332331	FY	active	G	X	X	X	O	O	O	O	O	O	

B) Proportions of correct answers (n = 17 participants)

IMAGE	SPECIES	ML LINK	AGE	MOLT	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Mean # of MINUTES
1	RIHU	ML112128831	0.82	1.00	0.94	0.94	0.94	1.00	1.00	1.00	0.82	0.18	0.47	0.06	5.1
2	VCHU	ML161385411	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.8
3	WEHU	ML255139331	1.00	1.00	0.71	0.82	0.35	0.59	0.59	1.00	1.00	1.00	1.00	1.00	3.2
4	BEHU	ML238319331	0.71	1.00	1.00	1.00	1.00	1.00	0.88	0.88	0.18	0.35	0.35	0.35	4.1
5	BBIH	ML251781011	1.00	0.77	1.00	0.82	0.71	0.71	1.00	1.00	1.00	1.00	1.00	1.00	3.2
6	BTMG	ML53554351	0.82	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	3.5
7	BBIH	ML66989701	0.71	0.71	0.65	0.65	0.59	1.00	1.00	1.00	1.00	1.00	1.00	1.00	3.9
8	RIHU	ML181183661	0.71	0.94	1.00	1.00	1.00	0.88	0.71	0.71	0.82	1.00	1.00	1.00	3.5
9	BEHU	ML212588541	0.82	0.94	1.00	1.00	1.00	1.00	1.00	0.12	0.65	0.65	1.00	1.00	4.0
10	BBEH	ML56665951	0.77	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	3.1
11	VCHU	ML54332331	0.82	0.82	0.12	0.77	0.77	0.59	0.65	1.00	1.00	1.00	1.00	1.00	3.9
	MEAN		0.83	0.93	0.86	0.91	0.85	0.89	0.89	0.88	0.86	0.83	0.89	0.86	3.7

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