The analysis of feather remains: evaluations and perspectives

(Tim G. Brom, The Netherlands)

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THE ANALYSIS OF FEATHER REMAINS: EVALUATION AND PERSPECTIVES

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ABSTRACT

Different methods of feather identification are discussed and evaluated, such as macroscopical comparison with bird skins, light-microscopy (LM), and scanning electron microscopy (SEM). Several new techniques are discussed which might be applied in the future, such as sectioning of feather parts, biochemical analysis of keratins, and analysis of chemical elements in feathers.

The results obtained in bird strike analysis in the Netherlands with LM investigation of feathers and feather fragments in combination with comparisons with bird skins are evaluated. 96% of all examined feather remains (n=1659) could be assigned to order, 71% to family, 64% to genus, and 58% to species. The Swift accounts for 24% of all identifications at species level. At family level, the Apodidae also score highest with 19%, followed by gulls and terns (Laridae & Sternidae) with 18%. At order level, the Passeriformes score highest with 40%, followed by the Charadriiformes with 26%.

INTRODUCTION

Collisions between birds and aircraft constitute a major problem to flight safety. Especially during the last decade the notion has become widely accepted that an adequate assessment of this problem by keeping accurate bird strike statistics is indispensable for taking the most appropriate preventive measures. Consequently, the search for diagnostic characters which can be used to identify those species most frequently involved, has been intensified. Besides preliminary biochemical studies on the analysis of blood and flesh remains (e.g., de Bont et al. 1986), attention has been focussed on the identification of feathers and feather fragments.

At several meetings of the Bird Strike Committee Europe (BSCE), methods of identification have been presented and evaluated, and, especially, after the formation of a Subgroup on Feather Identification within the Analysis Working Group of BSCE, microscopic identification of feathers has been discussed in detail.

The aim of this paper is to present an overview of the methods currently used and to discuss some of the results from the Netherlands. Further, the state of the art is evaluated for some techniques which might be applied to feather identification in the future.

EVALUATION OF METHODS OF FEATHER IDENTIFICATION

Macroscopical comparison of feathers

The traditionally used and most simple way of feather identification is that of comparing unknown feathers with a reference collection.

In order to be able to determine whether younger (and therefore less experienced) birds are more accident-prone than adults, a distinction between age classes is needed in bird strike statistics. Since no diagnostic characters are found in the micromorphology of feathers by which juvenile and adult birds can be distinguished, all information on the age of the bird depends on macroscopical criteria, and hence on the size and condition of the bird remains available for examination (see Table I). For some species hardly any differences in plumage exist between juvenile and older birds, whereas in others these differences are quite pronounced, at least during certain periods of the year.

Identification with light-microscopy (LM)

In the Netherlands, the identification of feathers with light-microscopy started in 1978. Based on the work of Chandler (1916) and Day (1966), an extensive LM study of the structure of downy barbules of body-feathers was performed, reference collections consisting of microscopical preparations and LM photographs were compiled, and a method

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was developed for identification purposes (Brom 1980, 1986). Most feather remains can be easily assigned to the order (and sometimes to the family) to which the bird belongs. Although some authors (Hargrave 1965, Messinger 1965) have worked successfully at the species level, the differences between closely related families and, especially, species are so small that constructing a key at this level is not feasible. At our institute, feathers are identified with the key presented in Brom (1986) in combination with comparisons with the reference collection of preparations and bird skins. In case one chooses for a collection of LM photographs, two sets of prints, one arranged according to species and the other arranged to similarity of characters, provide the best use of this aid. This system was found to be most satisfactory by Messinger (1965) in his study of feathers collected at archaeological sites.

Since 1978, LM investigation of bird remains in combination with the macroscopic method has been applied as a routine procedure. The effect of the introduction of the microscopic examination of feathers, together with a more conscientious search for even the smallest feather fragments by the airfield personel, has been discussed on several occasions (e.g. Brom & Buurma 1979, Buurma & Brom 1979, Buurma 1983). A drastic shift towards smaller and darker birds took place. At order level, the detection of passeriforms increased from 9% in 1960-1977 to 46% in 1978-1983. At species level, swifts increased from 11% in 1960-1977 to 30% in 1978-1983 (Brom 1984).

Scanning electron microscopy (SEM)

Earlier studies of feathers with scanning electron microscopy (Davies 1970, Stettenheim 1976, Reaney et al. 1978, Laybourne 1984, Robertson et al. 1984, Lyster 1985, Brom 1987) have clearly indicated that SEM can contribute toward the elucidation of functional, evolutionary, and developmental aspects of feather micromorphology as well as of taxonomic and diagnostic questions. The current research of the author, subsidized by the Netherlands Organization for Scientific Research (NWO), concerns the investigation of the phylogenetic significance of characters found in the microstructure of feathers. Although the primary goal of this project is to evaluate the evolutionary polarity of these characters in order to assess the relationships between the higher taxa of birds, it is beyond doubt that also the identification work will benefit from this study. With SEM the earlier described characters (Brom 1986) can be studied in more detail. It is envisaged that new diagnostic characters will become available and that, upon completion of a reference collection of several thousands of SEM photographs, this technique can be used as a routine procedure in the analysis of bird remains in the near future.

Study of the internal structure of feather parts

Preliminary studies (e.g. Auber 1957, 1964, Swales 1970, Dyck 1977, 1978) of the internal structure of feather parts (shaft, barbs, and barbules) suggest that the cellular configurations in the medulla and cortex constitute diagnostic characters for different groups of birds. According to Swales (1970), the internal structure of barbs is constant within a species, differs from related species only in detail, and includes a basic pattern common to all species which belong to the same family. However, until now studies in this direction have been limited and the results are far from sufficient to compile a reference collection. At present no diagnostic characters are available that could be used for comparisons with unknown feathers.

Biochemical analysis of feather keratins

Feathers, scales, and skins of birds consist mainly of ß-keratins, which are highly organized and complex proteins, extremely insoluble and resistant to chemical, physical, and biological agents (e.g. Brush 1976, Fraser & MacRae 1976). This stability is due to the cysteine bonds that form within the proteins.

One of the requirements of gel electrophoresis is that the proteins under study are soluble and it is the insolubility of feather proteins that forms a major drawback in keratin studies. The results are therefore of limited value and much is still to be learned about keratins and the evolutionary significance of electrophoretic patterns. Working along different lines of biochemical analysis, O'Donnell & Inglis (1974) and Knox (1980) presented results which indicate that feather keratin molecules do have considerable potential as a source of taxonomic information. The work that has been done so far indicates that keratins represent a group of closely related gene products. The reason for the large number of keratin monomers that are known to be synthesized remains a subject of speculation (Busch & Brush 1979, Brush 1985). Some of these monomers are species specific, whereas others are tissue specific and seem to be characteristic of various feather parts such as vane or rachis, or are typically found in the pennaceous portion or downy portion (Schroeder et al. 1955, Harrap & Woods 1967, Busch & Brush 1979, King & Murphy 1987). Since data on the amino acid composition of feathers are available for only a handful of species, diagnostic characters that could be applied in identification work are not known as yet.

Analysis of chemical elements in feathers

Feathers are composed primarily of carbon, nitrogen, oxygen, and hydrogen, but about 3 dozen additional chemical elements have been found and still others are suspected. From the work of Edelstam (1969) and Kelsall (1984) it is apparent that in some cases the chemical

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content of feathers reflects the composition of the local environment in which they were grown. Since the chemistry of geological areas varies, so too must the chemistry of tissues grown in different areas, particularly tissues such as feathers, which, once grown, form a closed system. Chemical profiles developed from single feathers thus may be diagnostic of the origins of birds which moult and grow new feathers in discrete areas. Colonially nesting geese in particular have been shown to be referable to their colony of origin through knowledge of the chemistry of feathers.

The methods of chemically analyzing feathers have included classical wet chemistry, atomic absorption/flame emission, and number of destructive and non-destructive multi-element analytical techniques, including the use of neutron activation, electron beams and X-rays. The potential application in bird strike analysis is evident, but the technique has yet to be field-tested on a wide basis.

RESULTS

The identification results from the Netherlands in the period that feather remains were analysed only macroscopically are as follows. In the period 1960-1975, 100% of all inspected remains (n = 119) could be assigned to a bird order, 92% to family, 88% to genus, and 74% to species. However, these results strongly depended on the skills of the investigator and on the condition of the bird remains. Smaller bird remains were neglected and therefore bird strike statistics were seriously biased by an over-representation of easily recognizable bird species.

The following is a summary of the analysis of 1659 feather remains of bird strikes in the period 1960-1987. All material dating from the period before 1978 has been rechecked both macroscopically and with LM by the author. Included are only those remains that have been received by the Zoological Museum, Amsterdam. Some 2% of the total number of remains is the result of bird strikes with civil aircraft. For these reasons the data presented in Table II should not be interpreted as representing the bird strike statistics of the Royal Netherlands Air Force. In total, 82 species of birds have been identified (eight of these came from collisions with civil aircraft outside Europe), belonging to 28 families and 12 orders. Although in all cases bird strikes could be confirmed by the presence of feather material in the samples, in 60 cases (= 4%) a more detailed identification than "Aves" was impossible. The other 1599 remains (=96%) could be assigned to order level, from which 1182 (=71%) were identified to family level, 1054 (= 64%) to genus, and 959 (= 58%) to species.

The species most frequently encountered is the Swift, with a total of 227. This is 14% of the total number of bird strikes in the period 1960-1987 (see Appendix). This bird is present in western Europe from mid April to September (the earliest collision occurred on 4

TABLE I. Age classes of 15 bird species most frequently identified in feather remains from bird strikes in the period 1960-1987, identified at the Zoological Museum, Amsterdam.

species	n	juvenile/ immature	adult	age unknown
1. Swift - Apus apus	227	0.4%	40%	60%
2. Lapwing - Vanellus vanellus	104	8%	7%	85%
3. Black-headed Gull - Larus ridibundus	66	41%	30%	28%
4. Buzzard - Buteo buteo	53	2%	7%	91%
5. Swallow - Hirundo rustica	51	16%	6%	78%
6. Skylark - Alauda arvensis	47	0%	0%	100%
7. Wood Pigeon - Columba palumbus	39	3%	3%	94%
8. Rock Dove/Feral Dove - Columba livia	34	9%	0%	91%
9. Common Gull - Larus canus	32	28%	56%	16%
10. Starling - Sturnus vulgaris	26	35%	4%	61%
11. Chaffinch - Fringilla coelebs	24	13%	0%	87%
12. House Martin - Delichon urbica	23	4%	9%	87%
13. Herring Gull - Larus argentatus	22	36%	64%	0%
14. Kestrel - Falco tinnunculus	16	25%	25%	50%
15. Partridge - Perdix perdix	15	7%	20%	73%

May, the latest on 5 September). Due to both its aerial way of life and its highly characteristic feather structure (Brom 1986), the Swift accounts for 24% of all identifications at species level (Table II). At family level, the Apodidae also score highest with 19%, followed by the gulls and terns (Laridae/Sternidae) with 18%. At order level, the Passeriformes score highest with 40%, followed by the Charadriiformes with 26% (Table II).

In all analyses of Swift remains (n=227), only one juvenile (= first calendar year) bird has been encountered, whereas at least 90 adults (= 40% of total) were involved. This result is in accordance with the fact that juvenile Swifts are only infrequently seen in feeding flocks in north-western Europe, because they migrate southward soon after they have left the nest (Cramp et al. 1985). Of all identified specimens of Herring Gull Larus argentatus (n=22), only one juvenile (first

TABLE II. I
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Sulidae

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Ardeidae

ANSERIFORME
Anatidae

ACCIPITRIFORM
Accipitridae

FALCONIFORME
Falconidae

GALLIFORMES
Phasianidae
Tetraonidae

CHARADRIIFORM
Charadriidae
Haematopodidae
Laridae/Sternidae
Scolopacidae

COLUMBIFORMES
Columbidae

STRIGIFORMES
Strigidae
Tytonidae

CAPRIMULGIFORM
Caprimulgidae

APODIFORMES
Apodidae

TABLE II. Identification results obtained by macroscopic and LM analysis of feather remains from bird strikes in the period 1960-1987, identified at ZMA.

	% of total number of identified families	% of total number of identified orders
PELECANIFORMES	--	
Sulidae		--
CICONIIFORMES	1%	
Ardeidae		1%
ANSERIFORMES	3%	
Anatidae		4%
ACCIPITRIFORMES	4%	
Accipitridae		5%
FALCONIFORMES	1%	
Falconidae		2%
GALLIFORMES	1%	
Phasianidae		2%
Tetraonidae		--
CHARADRIIFORMES	26%	
Charadriidae		10%
Haematopodidae		--
Laridae/Sternidae		18%
Scolopacidae		2%
COLUMBIFORMES	10%	
Columbidae		14%
STRIGIFORMES	1%	
Strigidae		--
Tytonidae		--
CAPRIMULGIFORMES	--	
Caprimulgidae		--
APODIFORMES	14%	
Apodidae		19%
PASSERIFORMES	40%	
Alaudidae		4%
Hirundinidae		7%
Fringillidae		3%
Emberizidae		--
Motacillidae		1%
Corvidae		2%
Prunellidae		--
Ploceidae		--
Sylviidae		--
Sturnidae		2%
Turdidae		4%

calendar year) bird was found, whereas seven were immatures (2nd - 3rd calendar year) and 14 adults (older than 3 calendar years). A more even distribution of age classes was found in the Black-headed Gull L. ridibundus: 19 were juveniles (1st and early 2nd calendar year), 14 were adults, whereas in 13 cases the remains were to scanty to determine the age of the bird. In strikes in which the Common Gull L. canus was involved, nine were juveniles, 18 adults, whereas of 15 birds the age could not be established (Table I).

CONCLUSION

The reliability of bird strike statistics greatly benefits from the cooperation between aviation authorities and professional biologists. In the Netherlands, the quality as well as the quantity of feather identifications have increased significantly during the last decade on account of three reasons:

1. The improvement of the general reporting standard in the Royal Netherlands Air Force
2. The introduction of the LM identification method as a routine procedure.
3. The skipping of identifications by non-biologists in order to keep unreliable data from the statistics.

The combination of LM examination and macroscopical comparisons with a reference collection of bird skins constitutes the most effective method at present. Whereas biochemical techniques are far from operational for bird strike analysis, the SEM method can be added as a highly effective tool to the routine procedure of feather identification. It is expected that the number of cases in which feather remains cannot be assigned to any group will be further reduced.

ACKNOWLEDGEMENTS

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APPENDIX. Species identified in macroscopic and LM analysis of feather remains from bird strikes in the period 1960-1987.

	number	% of total number of bird strikes	% of total number of identified species
PELECANIFORMES			
Sulidae			
Northern Gannet-Sula bassana	1	--	--
CICONIIFORMES			
Ardeidae			
Grey Heron-Ardea cinerea	5	--	1%
ANSERIFORMES			
Anatidae			
Mallard-Anas platyrhynchos	12	1%	1%
Teal-A. crecca	5	--	1%
Wigeon-A. penelope	2	--	--
Garganey-A. querquedula	1	--	--
Greylag Goose-Anser anser	1	--	--
White-fronted Goose-A. albifrons	1	--	--
Eider-Somateria mollissima	1	--	--
Goosander-Mergus merganser	2	--	--
ACCIPITRIFORMES			
Accipitridae			
Buzzard-Buteo buteo	53	3%	6%
Grashopper Buzzard Eagle-Butastur rufipennis	1	--	--
Black Kite-Milvus migrans	1	--	--
Honey Buzzard-Pernis apivorus	1	--	--
Sparrowhawk-Accipiter nisus	1	--	--
Goshawk-A. gentilis	1	--	--
FALCONIFORMES			
Falconidae			
Kestrel-Falco tinnunculus	16	1%	2%
Hobby-F. subbuteo	3	--	--
Merlin-F. columbarius	1	--	--
American Kestrel-F. sparverius	1	--	--
GALLIFORMES			
Phasianidae			
Partridge-Perdix perdix	15	1%	2%
Pheasant-Phasianus colchicus	2	--	--
Chukar Partridge-Alectoris chukar	1	--	--
Double-spurred Francolin-Francolinus bicalcaratus	1	--	--
Tetraonidae			
Black Grouse-Tetrao tetrix	2	--	--

CHARADRIIFORMES			
Charadriidae			
Lapwing-*Vanellus vanellus*	104	6%	11%
Golden Plover-*Pluvialis apricaria*	7	--	1%
Blackhead Plover-*Sarciophorus tectus*	1	--	--
Haematopodidae			
Oystercatcher-*Haematopus ostralegus*	13	1%	1%
Laridae			
Black-headed Gull-*Larus ridibundus*	66	4%	7%
Common Gull-*L. canus*	31	2%	3%
Herring Gull-*L. argentatus*	22	1%	2%
Lesser Black-backed Gull-*L. fuscus*	7	--	1%
Great Black-backed Gull-*L. marinus*	1	--	--
Sternidae			
Common Tern-*Sterna hirundo*	2	--	--
Black Tern-*Chlidonias nigra*	1	--	--
Scolopacidae			
Common Snipe-*Gallinago gallinago*	6	--	1%
Woodcock-*Scolopax rusticola*	2	--	--
Curlew-*Numenius arquata*	1	--	--
Black-tailed Godwit-*Limosa limosa*	4	--	--
Bar-tailed Godwit-*L. lapponica*	1	--	--
Ruff-*Philomachus pugnax*	1	--	--
Redshank-*Tringa totanus*	2	--	--
Knot-*Calidris canutus*	2		--
COLUMBIFORMES			
Columbidae			
Wood Pigeon-*Columba palumbus*	39	2%	4%
Rock Dove/Feral Dove-*C. livia*	34	2%	4%
Stock Dove-*C. oenas*	4	--	--
Turtle Dove-*Streptopelia turtur*	1	--	
Collared Dove-*S. decaocto*	1		
STRIGIFORMES			
Strigidae			
Long-eared Owl-*Asio otus*	2	--	
Tytonidae			
Barn Owl-*Tyto alba*	1	--	--
CAPRIMULGIFORMES			
Caprimulgidae			
Natal Nightjar-*Caprimulgus natalensis*	1	--	--
White-tailed Nightjar-*C. cayennensis*	1	--	--
APODIFORMES			
Apodidae			
Swift-*Apus apus*	227	14%	24%

PASSERIFORMES			
Alaudidae			
Skylark-Alauda arvensis	47	3%	5%
Hirundinidae			
Swallow-Hirundo rustica	51	3%	5%
House Martin-Delichon urbica	23	2%	2%
Sand Martin-Riparia riparia	1	--	--
Fringillidae			
Chaffinch-Fringilla coelebs	24	2%	3%
Brambling-F. montifringilla	1	--	--
Linnet-Carduelis cannabina	2	--	--
Siskin-C. spinus	1	--	--
Bullfinch-Pyrrhula pyrrhula	1	--	--
Emberizidae			
Yellowhammer-Emberiza citrinella	2	--	--
Motacillidae			
White Wagtail-Motacilla alba	6	--	1%
Yellow Wagtail-M. flava	1	--	--
Meadow Pipit-Anthus pratensis	4	--	--
Tree Pipit-A. trivialis	1	--	--
Corvidae			
Jackdaw-Corvus monedula	6	--	1%
Rook-C. frugilegus	4	--	--
Carrion Crow-C. corone	1	--	--
Prunellidae			
Dunnock-Prunella modularis	1	--	--
Ploceidae			
House Sparrow-Passer domesticus	3	--	--
Sylviidae			
Blackcap-Sylvia atricapilla	1	--	--
Sturnidae			
Starling-Sturnus vulgaris	25	2%	3%
Turdidae			
Fieldfare-Turdus pilaris	14	1%	2%
Redwing-T. iliacus	10	1%	1%
Song Thrush-T. philomelos	7	--	1%
Blackbird-T. merula	5	-	1%
Mistle Thrush-T. viscivorus	1	--	--
Wheatear-Oenanthe oenanthe	1	--	--
Robin-Erithacus rubecula	1	--	--

Report o
Spinner I

(Shinya Shima,