FIGURE 1. Mean hourly entrance–departures of Purple Martins for three days in the post-breeding stage at the end of the breeding cycle. These data, collected in 1966 at Elk Island National Park, involved a yearling male that began defending the cavity 23 July, a female that joined the defense 27 July, and a lone adult male defending the cavity on 30 July.

"remember" the exact location of nest boxes, since in the spring, if the box has not yet been put up, they will flutter around where it was the previous year. Nice (1937) has shown that territorial behavior in the Song Sparrow in the late summer has the function of fixing in the bird an individual territory to which it later returns in the spring. Similarly, Purple Martins may learn the location of available nest sites within a 10-mile radius by post-breeding activity.

LITERATURE CITED

ALLEN, R. A., AND M. M. NICE. 1952. A study of the breeding biology of the Purple Martin (*Progne subis*). Amer. Midland Nat. 47:606–665.

BREWSTER, W. 1925. The birds of the Lake Umbagog region of Maine. Bull. Mus. Comp. Zool. 66: 276–305.

BUMP, G., R. W. DARROW, F. C. EDMINSTER, W. F. CRISSEY. 1947. The Ruffed Grouse, life history,

propogation, management. New York St. Conserv. Dept., Buffalo.

JOHNSTON, R. F., AND J. W. HARDY. 1962. Behavior of the Purple Martin. Wilson Bull. 74:243–262.

MORLEY, A. 1943. Sexual behaviour in British birds from October to January. Ibis 85:132–158.

NICE, M. M. 1937. Studies in the life history of the Song Sparrow. Vol. I. A population study of the Song Sparrow. Trans. Linnaean Soc. New York 4:1–247. (Reprinted in 1964 by Dover Publications, New York.)

OLMSTEAD, R. 1955. Observations on Purple Martins. Kansas Ornithol. Soc. Bull. 6:8–10.

PETERSON, A. J. 1955. The breeding cycle in the Bank Swallow. Wilson Bull. 67:235–286.

SOUTHERN, W. E. 1968. Experiments on the homing ability of Purple Martins. Living Bird 7:71–84.

PELLET REGURGITATION BY CAPTIVE SPARROW HAWKS (*FALCO SPARVERIUS*)

THOMAS G. BALGOOYEN[1]

Department of Biological Sciences
San Jose State College
San Jose, California 95114

When ingested by raptorial birds, indigestible materials such as hair, bone, insect exoskeletons, or reptile scales may be regurgitated in the form of pellets.

[1] Present address: Museum of Vertebrate Zoology, University of California, Berkeley, California 94720.

Food habit studies of birds of prey frequently are based on analysis of pellet materials. Table 1 summarizes observations on rates of pellet regurgitation by various raptors, as reported by other authors. Additional variables include the size, weight, and composition of pellets in relation to different kinds and amounts of food eaten. The mechanisms of timing and casting of pellets are not well understood. This paper reports on the rate (duration of time between first ingestion of food and pellet ejection), size, weight, and number of pellets produced after a feeding by captive Sparrow Hawks fed known amounts of different foods.

Four Sparrow Hawks were placed in individual wooden stalls 240 cm high, 45 cm long, and 61 cm deep (fig. 1). Welded wire fabric served as flooring
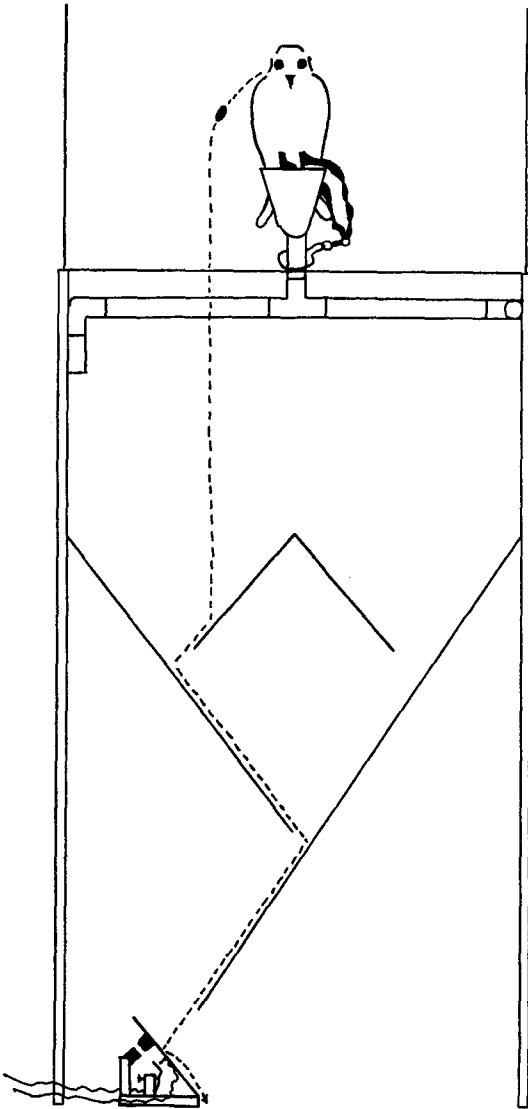
FIGURE 1. One of the experimental stalls. Each bird was tethered by jesses and a shower curtain hook to a cement perch. Regurgitated pellets passed through the wire floor and baffle system onto a recording treadle below. The force of a falling pellet overcame the opposing magnetic forces from two small magnets which allowed an electrical contact. As the pellet rolled from the treadle, the magnetic force reset the treadle.

through which pellets could pass. Opaque partitions were erected between the hawks. Cast pellets dropped through a series of baffles that diverted wind currents, collected fecal matter, and guided pellets onto a recording treadle (fig. 1). Pellets falling on the treadle were recorded on an 8-min grid of an Ester-line-Angus Recorder.

The whole experiment was conducted in an indoor chamber, with light on at 08:00 and off at 18:00. Pellets were measured for length and width to the nearest millimeter. After being air-dried for one week at room temperature, pellets were weighed to the nearest 0.01 g. Time of feeding (about 09:00 until food was refused), amount of food ingested, tempera-

ture (°C), and per cent of relative humidity were recorded.

To discover the effects of different indigestible materials on the rate and number of pellets regurgitated, three feeding experiments of 20 days each were devised. Experiment I employed albino mice, with hair and bone the potential material of pellets. (It was found in field trials that albino mice were accepted as readily as brown mice.) In Experiment II, pieces of cotton, the material of pellets, were pushed inside small pieces of beef heart with forceps. During Experiment III, Sparrow Hawks were fed White-crowned Sparrows (*Zonotrichia leucophrys*), Golden-crowned Sparrows (*Z. atricapilla*), House Sparrows (*Passer domesticus*), and House Finches (*Carpodacus mexicanus*). Because all birds were small passerines, this variable was believed insignificant.

To determine whether the rate and number of ejections, weight of food ingested by hawks, and dimensions and weight of the pellets of the three experiments differed significantly ($P < 0.05$), the data were compared by Student's t test.

RESULTS AND DISCUSSION

Regardless of the material ingested by Sparrow Hawks, the time of regurgitation averaged 21 hr, 33 min after food ingestion (table 2), or approximately 1 hr, 30 min before the artificial sunlight came on. Rates of regurgitation, in short, appeared to be predetermined.

Individual Sparrow Hawks produced similar numbers of pellets throughout all experiments (table 3). However, significantly more multiple ejections occurred with meals of mice (7) than with meals of either cotton and beef heart (0), or birds (1).

Sparrow Hawks tended to ingest more indigestible materials and produce longer, wider, and heavier pellets after eating mice than after eating other test foods. They usually regurgitated one pellet after eating, or occasionally two when a considerable volume of indigestible material had been consumed.

The dry weight of pellets differed significantly because equal volumes of hair, cotton, and feather weigh different amounts. Hair, feather, and cotton pellets could be sorted according to decreasing weights, in that order.

On occasion direct observation of multiple pellet regurgitation was made. When two or three pellets were regurgitated, the smallest was regurgitated last. From these observations it is hypothesized that the need for multiple pellet ejection arises when the amount of indigestible material exceeds the volume of the ventriculus. When this predetermined amount is reached, one complete pellet is regurgitated. The remaining material may form another pellet the same or smaller size than the first or complete pellet, and smaller pellets could be termed incomplete. The size and shape of pellets would be dependent upon the structure and function of the ventriculus (Reed and Reed 1928).

Chitty (1938) found that the length of time a pellet was retained increased logarithmically with the weight of the meal. On the contrary, the present study seemed to suggest that the time of regurgitation was largely independent of volume or weight of food consumed. While more study is needed, it is reasonable to conclude that factors affecting the rate of regurgitation lie outside these variables, and that light regime and/or feeding time are the suspected determinants of when a pellet will be cast.

By multiplying the linear dimensions of pellets, mean ($\pm$ SD) volumes of 1.59 ± 1.18 cm^3 ($n = 222$) for singly ejected pellets and 5.86 ± 2.10 cm^3 ($n = 8$)

TABLE 1. Reported rates of pellet regurgitation by various raptors.

Source	Raptor	Time or rate of regurgitation (hr after eating)
Errington (1930)	Marsh Hawk (*Circus cyaneus*)	each day before 08:00
Bond (1936)	falcons	each morning
	small falcons	2nd pellet in p.m.
Ticehurst (1935)	Barn Owl (*Tyto alba*)	within 12
Wallace (1948)	Barn Owl	8–24
		5½–12
Banks (1884)	Great Horned Owl (*Bubo virginianus*)	24–72
Reed (1925)	Great Horned Owl	24
Reed and Reed (1928)	Great Horned Owl	12–24
Errington (1930)	Great Horned Owl	19–24
Errington (1938)	Great Horned Owl	72
Howard (1958)	Great Horned Owl	32¾
Grimm and Whitehouse (1963)	Great Horned Owl	16
Errington (1930)	Barred Owl (*Strix varia*)	about 10
Sensenig (1945)	Barred Owl	within 8
Chitty (1938)	Short-eared Owl (*Asio flammeus*)	12
Brooks (1929)	all raptors	within 12
Darwin (1859)	all raptors	12–20

for multiply ejected pellets were calculated. This highly significant difference indicates a need for multiple pellet ejections to eliminate large volumes of indigestible material. There was evidence to suggest that the occurrence of multiple pellet regurgitation may retard the time of ejection. Pellets in the case of multiple ejection were retained 50 min longer, on the average, than when only one pellet was ejected. Perhaps the rate of pellet regurgitation is slowed by the presence of a quantity of indigestible material great enough to form two or more pellets (threshold effect), because large amounts of material are believed to cause congestion in the ventriculus. Consequently the forming of two or more pellets from a large, tightly compacted mass of residual material can be assumed to consume more time; this would account for the delay in ejection of multiple pellets. Seven of the eight multiple pellet ejections occurred during the mouse experiment after Sparrow Hawks had ingested the greatest amounts of indigestible materials.

cotton than mice or birds, but with meals of mice, they ingested more pellet-forming materials which resulted in longer, wider pellets and more multiple ejections.

Individual Sparrow Hawks produced a similar number of pellets throughout all experiments. The most common number of pellets regurgitated was one per day. Multiple pellet ejection was dependent on an unusually large amount of indigestible material in the ventriculus. Evidence showed multiple pellet ejection slowed the rate of regurgitation, probably because of the extra time needed to form two or more pellets from a large indigestible mass.

Understanding that the rate and number of pellet regurgitations are independent of the weight and kind of food ingested by Sparrow Hawks allows focusing of attention upon the factors of light regime and/or time of feeding of hawks as they affect the rate of pellet regurgitation.

SUMMARY

Under experimental conditions, the rate of pellet regurgitation did not differ significantly after Sparrow Hawks had ingested meals of mice, beef heart and cotton, or birds. The mean time of pellet ejection was 21 hr and 33 min after eating.

Pellets were similar in weight when formed from the same kind of food, but differed with the kinds of food eaten.

Sparrow Hawks tended to eat more beef heart and

TABLE 2. Characteristics of Sparrow Hawk pellets during three feeding experiments of 20 days each.[a]

Experimental food	Ingested food (80 meals) Weight (g)	Time before ejection (hr:min)	No.	Pellet characteristics Weight (g)	Length (mm)	Width (mm)	"Volume" (mm³)[b]
Mice	15.4 ± 3.43	21:32 ± 1:02	83	0.27 ± .15	19.0 ± 6.42	11.2 ± 1.75	239.9 ± 121.75
Cotton and beef heart	23.8 ± 4.13	21:27 ± 0:35	75	0.11 ± .06	13.0 ± 3.61	9.4 ± 1.41	125.6 ± 50.58
Birds	16.8 ± 3.20	21:42 ± 0:28	72	0.17 ± .09	14.5 ± 5.27	8.4 ± 1.36	121.7 ± 105.48

[a] $\bar{x} \pm$ SD.
[b] Pellet length (mm) × pellet width (mm) × pellet depth (mm).

TABLE 3. Numbers of pellets per day regurgitated by Sparrow Hawks during three feeding experiments of 20 days each.

Sparrow Hawks	Experimental food and no. pellets/day												Σ	x̄ ± SD
	Mice					Cotton with beef heart			Birds					
	0	1	2	3	Σ	0	1	Σ	0	1	2	Σ		
♀	1	18	1		20		20	20	2	18		18	58	18.7 ± 0.9
♀	2	18			18		20	20	2	18		18	56	18.7 ± 0.9
♂		14	5	1	27	3	17	17	5	14	1	16	60	20.0 ± 4.9
♂	2	18			18	2	18	18		20		20	56	18.7 ± 0.9
Σ					83			75				72	230	
x̄ ± SD			20.8 ± 3.7			18.9 ± 1.3			18.0 ± 1.4					

I am thankful to L. R. Mewaldt for the use of laboratory and space equipment.

LITERATURE CITED

BANKS, J. W. 1884. The Great Horned Owl in confinement. Auk 1:194–195.

BOND, R. M. 1936. Eating habits of falcons with special reference to pellet analysis. Condor 38:72–76.

BROOKS, A. 1929. On pellets of hawks and owls. Condor 31:222–223.

CHITTY, D. 1938. A laboratory study of pellet formation in the Short-eared Owl (Asio flammeus). Proc. Zool. Soc. London 108A:271–287.

DARWIN, C. 1859. On the origin of species by means of natural selection, or preservation of favored races in the struggle for life. John Murray, London.

ERRINGTON, P. L. 1930. The pellet analysis method of raptor food habits study. Condor 32:292–296.

ERRINGTON, P. L. 1938. The Great Horned Owl as an indicator of vulnerability in prey populations. J. Wildl. Mgmt. 2:190–205.

GRIMM, R. J., AND W. M. WHITEHOUSE. 1963. Pellet formation in a Great Horned Owl: a roentgenographic study. Auk 80:301–306.

HOWARD, W. E. 1958. Food intake and pellet formation of a Horned Owl. Wilson Bull. 70:145–150.

REED, B. P. 1925. Growth development and reactions of young Great Horned Owls. Auk 42:14–31.

REED, C. I., AND B. P. REED. 1928. The mechanism of pellet formation in the Great Horned Owl (Bubo virginianus). Science 68:359–360.

SENSENIG, E. C. 1945. The formation of pellets by the Barred Owl. Wilson Bull. 57:132.

TICEHURST, C. B. 1935. On the food of the Barn Owl and its bearing on Barn Owl population. Ibis 5:329–335.

WALLACE, G. J. 1948. The Barn Owl in Michigan. Tech. Bull. Agri. Exp. Sta. Michigan St. Coll. 280:1–61.

FIRST NESTING RECORD FOR THE FRIGATEBIRD (FREGATA MINOR) IN THE MAIN HAWAIIAN ISLANDS

ROBERT J. SHALLENBERGER

AND

J. PETERSON MYERS

Oceanic Institute
Waimanalo, Oahu, Hawaii

Moku Manu lies ¾ mile off Ulupau head on the east shore of Oahu, Hawaii. It is one of several small islets which serve as breeding grounds for Hawaiian seabirds. Entry without permit is prohibited by the Hawaii State Department of Fish and Game.

A short visit (08:00–14:00) was made to Moku Manu on 17 July 1970. One nest containing a Frigatebird (Fregata minor) chick was discovered near the shoreline along the south side of the island (fig. 1). No adults were observed at the nest, and we estimated the chick's age at approximately 1–1½ months. The nest was located within 15 ft of Red-footed Booby (Sula sula) nests containing chicks of approximately the same age. The size, condition, and location of the Frigatebird's nest indicated that it had possibly been

FIGURE 1. Frigatebird nest found on Moku Manu on 17 July 1970.

used by boobies in former years. It is also interesting to note that this nest was on the extreme periphery of the local booby colony.

Adult Frigatebirds (estimated total population, 400–500) roosted in dense groups 75–100 yards away in