appreciable residues of pollutants may be present. Polychlorinated biphenyls (PCBs) have been found on the surface of polystyrene spherules, apparently absorbed from seawater, in a concentration of five parts per million (Carpenter et al. 1972), and it may be assumed that organochlorines are associated with other oceanic plastic items. Measurable residues of DDT, DDE, and PCBs were detected in visceral fat from Black-footed and Laysan albatross on Midway (Fisher 1973). Although the origin of such ingested pollutants may be in the North Pacific food chain, it may also be associated with plastics ingested by albatross.

Our stay on Midway Islands was supported by a National Science Foundation Grant (PCM 12351-A01) administered by Dr. G. C. Whittow. We are grateful to CDR Kuhneman, Commanding Officer, for assistance during our stay at the U.S. Naval Air Facility, Midway Island. Special thanks to ENS Immel and the base game warden staff for invaluable aid and transportation to Eastern Island. We thank Elizabeth Flint, Department of Biology, U.C.L.A., for collecting fresh castings on French Frigate Shoals and G. H. Balazs for the use of unpublished data. We also thank Craig Harrison for his critical review of the manuscript.

LITERATURE CITED

CARPENTER, E. J., S. J. ANDERSON, G. R. HARVEY, H. P. MIKLAS, & B. B. PECK. 1972. Polystyrene spherules in coastal waters. Science 178: 749–750.

DAY, R. H. 1980. The occurrence and characteristics of plastic pollution in Alaska's marine birds. Unpublished M.S. thesis, College, Alaska, Univ. Alaska.

FISHER, H. I. 1973. Pollutants in North Pacific albatrosses. Pacific Sci. 27: 220–225.

———, & J. R. FISHER. 1972. The oceanic distribution of the Laysan Albatross, *Diomedea immutabilis*. Wilson Bull. 84: 7–27.

HARRISON, C. S., & T. S. HIDA. 1980. *In* Proc. Status Resource Investigations in the Northwest Hawaiian Islands (R. W. Grigg and R. T. Pfund, Eds.). Honolulu, Hawaii, Sea Grant, Univ. Hawaii.

HAYS, H., & G. CORMONS. 1974. Plastic particles found in tern pellets, on coastal beaches and at factory sites. Mar. Pollut. Bull. 5: 44–46.

KENYON, K. W., & E. KRIDLER. 1969. Laysan albatross swallow indigestible matter. Auk 86: 339–343.

OHLENDORF, H. M., R. W. RISEBROUGH, & K. VERMEER. 1978. Exposure of marine birds to environmental pollutants. Washington, D.C., U.S. Dept. Interior, Fish and Wildlife Service, Wildlife Research Report 9.

PARSLOW, J. L. F., & D. J. JEFFRIES. 1972. Elastic thread pollution of puffins. Mar. Pollut. Bull. 3: 43–45.

ROTHSTEIN, S. I. 1973. Plastic particle pollution of the surface of the Atlantic Ocean: evidence from a seabird. Condor 75: 344–366.

Received 9 February 1981, accepted 21 April 1981.

Ficus ovalis Seed Predation by an Orange-chinned Parakeet (*Brotogeris jugularis*) in Costa Rica

DANIEL H. JANZEN
Department of Biology, University of Pennsylvania, Philadelphia, Pennsylvania 19104 USA

Parrots and parakeets (Psittacidae) are often thought of as frugivorous, and fruits are often listed as the food of parrots observed feeding in the wild (e.g. Forshaw 1978, Parrots of the World, London, David and Charles, Newton Abbot). On the other hand, from observing parrots of all sizes feeding in the wild in Central America and in captivity, I have the impression that a parrot is rarely frugivorous and usually preys on the seeds inside the fruit, whether the fruit is immature or mature. I have never encountered an unambiguous case of seed dispersal by parrots. Psittacids that eat figs, however, are often mentioned to me as potential exceptions to this generalization, and the tiny Orange-chinned Parakeet

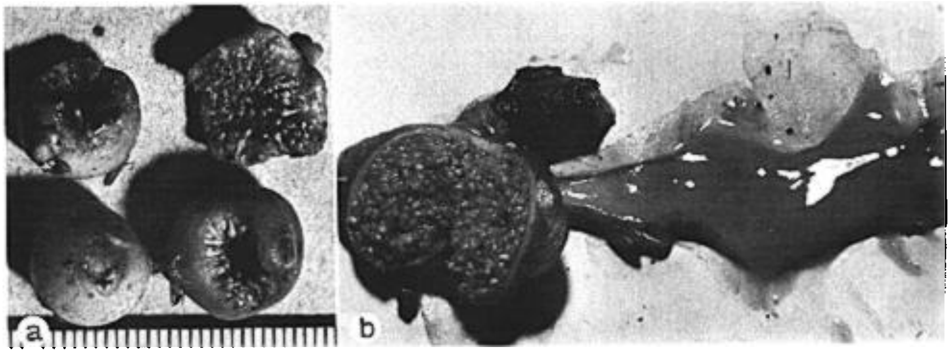

Fig. 1. **a.** Ripe fruits of *F. ovalis* that have had a piece bitten out of them by *Brotogeris jugularis* before being dropped (scale is in mm). **b.** Gizzard of an adult male *Brotogeris jugularis* (top, cut open) stuffed with nested seed coat fragments of *F. ovalis*; upper intestine (bottom) split open lengthwise to expose the purée of finely ground seed contents and fruit pulp.

(*Brotogeris jugularis*) is often the example given in Costa Rica. To determine whether *B. jugularis* is primarily a seed predator rather than disperser of fig seeds, I dissected one that had been feeding on figs for a morning. The results described below confirm my initial impression that *B. jugularis* is acting as a predator on fig seeds, even though it also consumes some fruit pulp.

A large tree of *Ficus ovalis* grows near the southwest corner of the historic Casona in Santa Rosa National Park. The Park lies about 25 km south of the town of La Cruz, between the Pan-American Highway and the Pacific ocean, in northwestern Guanacaste Province, Costa Rica (0–350 m elevation). This tree usually produces a large crop of several hundred thousand 9–15-mm diameter pink to red spherical figs in the early rainy season (June–July) and at the end of the rainy season (December–January) (Janzen 1979a, Biotropica 11: 48; 1979b, Biotropica 11: 127). Many vertebrates eat these figs while the fruits are in the tree crown and after they fall. A flock of 50–100 Orange-chinned Parakeets often arrives about dawn (0530) and feeds and socializes in the tree crown until late morning. For several hours an individual parakeet walks along the branches and branchlets, reaching out with its bill to pick single ripe fruits, usually in the ivory to dark pink color stage. At this stage the occupant fig wasps have left the fruit, but it is still only partly softened. The bird bites a piece out of the fruit that is about one fifth

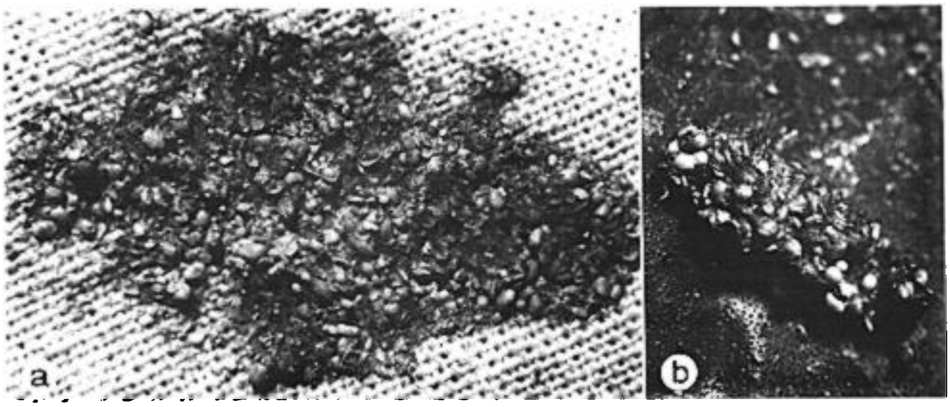

Fig. 2. **a.** The rare type of fecal splat of *B. jugularis* when feeding on *F. ovalis* fruit pulp and seeds; the feces contains no viable seeds and probably contains the bulk of a bolus of seed coats voided by the gizzard. **b.** Relatively dry bat feces rich in intact *F. ovalis* seeds, largely undigested fig pulp fiber, and seeds that contained fig wasps (two seeds have conspicuous exit holes).

of the fruit's surface area (Fig. 1a) and then drops the fruit. On occasion it holds the fig in one foot while taking repeated bites. The bird manipulates the piece of fig for only a few seconds and then drops the remains. It appears to be swallowing pieces of the fruit, a behavior that gives rise to the impression that it is swallowing intact seeds.

On 7 January 1980, I shot a male of one of these birds at 1300, after it had been feeding in the tree all morning. The crop contents were massaged out and the bird dissected. The autopsy was completed 30 min after shooting the bird. The crop contained about 6 cc of beige liquid fig fruit pulp thoroughly mixed with numerous apparently intact and viable fig seeds and a few broken large seed fragments. The seeds were hard, roughly spherical, and 1–2 mm in diameter. Each seed and large seed fragment was covered by the clear gelatinous sheath that swells up around seeds of *Ficus ovalis* when they are immersed in water. There were 2,695 seeds and 358 large seed fragments in the crop.

The gizzard contained the seed coats of approximately 1,575 seeds (Fig. 1b). It was completely filled. In addition, it contained 171 apparently intact seeds. Microscopic inspection, however, showed each of these seeds to be cracked. Most seed coats were halves or other large pieces and were tightly nested, as would be a large number of broken bird eggshells haphazardly but tightly packed into a box. There were no conspicuous masses of seed contents or fruit pulp in the gizzard.

The small and large intestine was plumply filled with a very fine-grained, beige-colored purée (Fig. 1b), with a few traces of finely ground seed coats scattered along the intestinal tract. Additionally, there were 16 apparently intact *F. ovalis* seeds in the intestine. Microscopic examination, however, showed all 16 to be cracked. None of them had the gelatinous sheath around them, and none germinated when rinsed and placed on moist toweling for 15 days (intact *F. ovalis* seeds from bat feces germinate in about a week when placed on moist toweling).

Upon re-examination of the seeds in the crop, I found that each of the 2,695 apparently intact seeds was cracked. The parakeet had cracked each with its bill before swallowing it, probably with the tongue and the knife-edge of the lower bill working against the anvil of the buccal side of the upper bill (as do captive *B. jugularis*). I suspect that simply cracking the seed rather than shearing it in half is a faster action than biting it all the way through, both because of a shorter bill movement and because there are then fewer pieces for the parakeet to control. The muscular walls of the gizzard then crushed the cracked seeds against one another (there was no grit in the gizzard). Acting as the grinding surface in the gizzard, the seed coats finely pulverized both the seed contents and the fruit pulp. This purée was then passed on to the intestine.

I watched the *B. jugularis* defecate while in the fig tree and collected their feces on cloth sheets and on leaves. There were two kinds of droppings. The most common were liquid with fine beige particles and contained occasional small fragments of seed coat. The other type was the same but contained a large quantity of seed coat fragments (Fig. 2a). The parakeets apparently retained the seed coats in the gizzard for a digestive bout and then passed them on as a bolus. This bolus probably passed rapidly through the intestinal tract, and its broken seed coat edges had minimum contact with the intestinal mucosa. I found no intact seeds in the parakeet fecal splats on leaf and branch surfaces beneath the tree.

The bat feces below the *F. ovalis* tree were generated by phyllostomatid bats and were quite different from those of *B. jugularis* (Fig. 2b). The bat feces contained intact viable seeds, seeds with wasp exit holes, florets from inside the fig, and fibrous fruit pulp and rind. Intact seeds from the bat feces germinated in moist soil. The bats were clearly consuming whole fruits or large pieces and only very superficially processing the contents. *B. jugularis,* on the other hand, contained nothing but clean fruit pulp and seeds that were once intact. It must therefore have eaten only the pulp that is interior to the fig epidermis and exterior to the outermost layer of seeds. Furthermore, it must have orally examined each seed to determine whether it was intact or had a wasp exit hole or wasp inside. I suspect that after it bit a piece out of the fruit wall, it bit many seeds one at a time. Upon encountering a solid seed (one free of wasp damage), it bit hard enough to crack it and then removed only that seed from the fruit fragment. In the meantime, it also bit tiny pieces of pulp out of the fruit wall.

In a sample of 20 figs taken from the branches where the parakeets were selecting fruit, a minimum of 36% of the seeds had been killed by wasps, and the average was 77% per fig; there was an average of 47.2 good seeds per fig in this sample. Calculating backwards from the 4,815 originally intact seeds in this parakeet, the bird would have to have picked 510 figs that morning. This assumes that the parakeet bit 20% out of each fig, that the fig fruits contained an average of 47.2 good seeds, and that the parakeet made no mistakes. At this rate, a flock of 100 *B. jugularis* would pick 51,000 figs per morning, or 15% of the original crop of about 780,000 figs in the fruit crop in which the parakeet was feeding.

In summary, it appears that to a *Ficus ovalis* fig crop, the Orange-chinned Parakeet is a fruit pulp consumer and a seed predator, but not a seed disperser. The fruit fragments it drops below the parent tree, however, may be later eaten by a nonvolant seed disperser. *B. jugularis* may therefore not only kill fig seeds but alter the nature of the seed shadow by directing seeds into a different portion of the disperser coterie than would have swallowed them had the ripe figs been left in the crown for arboreal and volant vertebrates to eat.

This study was supported by NSF DEB 80-11558 and the Servicio de Parques Nacionales de Costa Rica. The manuscript was constructively reviewed by G. Stevens and W. Hallwachs. It is dedicated to the surviving mate of the parakeet that was sacrificed.

Received 15 September 1980, accepted 7 April 1981.

Rete Mirabile Ophthalmicum in Hawaiian Seabirds

TED N. PETTIT, G. CAUSEY WHITTOW, AND GILBERT S. GRANT
Department of Physiology, John A. Burns School of Medicine, University of Hawaii,
Honolulu, Hawaii 96822 USA

The central role of the rete mirabile ophthalmicum (RMO) of birds in maintenance of a body-to-brain temperature difference has been well documented in several recent reports (Kilgore et al. 1979, Bernstein et al. 1979a, 1979b). The anatomical arrangement for counter-current heat exchange between the cerebral arterial supply of blood and cooler venous blood from evaporative respiratory membranes and the cornea has been reported for a number of species (Richards and Sykes 1967, Lucas 1970, Kilgore et al. 1976, Crowe and Crowe 1979), but no anatomical studies of the RMO in tropical seabirds have been reported. This study was undertaken to examine the anatomy of the RMO in some Hawaiian seabirds in view of the demanding and stressful environmental conditions encountered in the tropics.

The species, number of specimens examined, and collection points are listed in Table 1. Dissections were performed on fresh specimens in most cases. A binocular dissection microscope was used and annotated drawings made as the dissection progressed. The procedure involved the removal of the cranial skin and feathers with careful manipulation of the ventral intrasphenoid segment of the cerebral carotid arteries to expose the intercarotid anastomosis and external ophthalmic, external carotid, and internal carotid branches of the common carotid artery. After noting the configuration of the carotid segments, the dissection was extended to the temporal and orbital regions to expose the ophthalmic rete and rami of the external ophthalmic artery.

In all species examined, a RMO was found in a shallow depression in the temporal region of the head, lying in close contact with the skull between the otic process of the quadrate and the orbital ridge. A diagram of the arterial RMO for six species of Hawaiian seabirds is presented in Fig. 1. The RMO is composed of an arterial rete supplied by the external ophthalmic branch of the common carotid and a medial venous rete composed of branches of ophthalmic veins supplying venous blood to the cavernous sinus. The external ophthalmic artery crosses the middle ear in a canal dorsomedial to the oval window and emerges to subdivide into four rami: temporal, supraorbital, ophthalmic, and infraorbital. All rami and the inferior alveolar artery contribute vessels to the arterial component of the RMO.

The common carotid arterial supply to the RMO is derived from a unique intercarotid anastomosis characteristic of avian species (Baumel and Gerchman 1968). Two of the three principal patterns described by Baumel and Gerchman were observed (Table 1). The functional differences in the patterns of intercarotid anastomosis are not clear, but they may reflect differences in the amount of blood available for circulation to the RMO. Birds do not possess a cerebral arterial circle of Willis comparable to mammals, but the intercarotid anastomosis may serve as an effective substitute with the potential for shunting blood from one side to the other.

The existence of common morphologies for the RMO of these Hawaiian seabirds suggests that counter-current heat exchange is the common underlying mechanism for cooling the brain, as it is in most avian species. The advantages of tolerating an increase in body temperature while maintaining brain temperature below body temperature enhances a bird's tolerance of environmental heat stress. These advantages have been stated previously (Kilgore et al. 1976). In addition, the advantage of protecting brain tissue from thermal extremes during heat-stress associated with flight (Bernstein et al. 1979b) must be considerable for pelagic, migratory species. Based on morphology alone, the effectiveness of heat exchange