SHORT NOTES

Gastroliths assist digestion in shags

Small stones or pebbles are often noticed in stomachs or food samples taken from shags and cormorants (e.g. Stone 1901, van Tets 1968, Wright 1975, Duffy & Laurensen 1983). The usual explanations for them are that stones are an artifact of feeding, that shags actively select stones for ballast or as aids in swimming, or that stones are used as adjuncts in digestion. As part of a larger study on the ecology of Fuego-Patagonian cormorants and shags, I obtained food samples from four species, and I examine here the frequency of stones in shag stomachs and their possible significance.

METHODS

I collected diet samples from 364 birds of four species (Imperial Shag *Leucocarbo atriceps*, Rock Shag *Stictocarbo magellanicus*, Red-legged Shag *S. gaimardi*, and Olivaceous Cormorant (*Hypoleucos olivaceus*) from several localities throughout Fuego- Patagonia (Puerto Melo, Puerto Deseado, Monte Leon, Ushuaia, Argentina, and Isla Chiloe in Chile). Various aspects of the natural history and systematics of these species are given in Siegel-Causey (1986a, b, 1987, 1988). Birds were collected while they were feeding or returning to the colony. I examined the stomach and oesophageal contents of each bird, and I saved all contents for later examination. In all, I obtained 184 food samples, 36 of which contained stones.

I recorded the weight, volume, and composition (including stone weight and volume) of each food sample, as well as the bird's identity, sex, and body weight. I fixed food samples in buffered 5% formalin, and identified food items in the laboratory with the help of several experts (see Acknowledgements). For this analysis, foods were classed as fish, crustaceans, and other invertebrates, and by condition (whole, fragments or bones, mush).

TABLE 1 — Frequency of food types and stones in shag stomachs

Species	Number of birds collected	Number of birds with fish	crustaceans	stones
Imperial Shag	199	42	22	11
Rock Shag	116	51	33	21
Red-legged Shag	49	19	1	0
Olivaceous Cormorant	25	17	1	4

RESULTS

Stones were not common in the shags I collected, and the overall frequencies varied widely (Table 1). I found a significant relationship between stone weight and the weight of stomach contents, but only in Rock Shags and only with crustaceans ($r = 0.533$, $df = 14$, $P = 0.039$). The total weight

of stones in stomachs ranged from 0.01% to 1.6% of body weight, with averages of 0.1% (Imperial Shag), 0.2% (Olivaceous Cormorant), and 0.3% (Rock Shag). No other regressions of weight of stones in stomachs on individual body weight were significant, nor were comparisons of stone presence or absence between sexes, age classes, or collection habitat.

Most consumed food was partly or heavily digested; however, in 37 stomachs the food (mostly fish) was barely digested or untouched. I found no stones in these 37 stomachs or in those with partly digested food. Instead, stones were with food in the last stages of digestion. Three of the Rock Shags I collected had only small stones in the lower oesophagus and only food in the stomach. The food in these birds was fully digested and comprised only fish bones or crustacean exoskeletons. Altogether, I found stones more often in birds that had fed well before collection than in birds that had recently fed ($x^2 = 23.04$, df = 1, $P<0.001$).

DISCUSSION

This evidence does not support the notions that stones are feeding artifacts, that they are used to decrease buoyancy, or that they are used to maintain or influence swimming. Instead, I infer that stones are used after feeding as a gastric mill to assist in breaking down inedible bones and chitinous remains before they are ejected in pellets. (See Duffy & Laurenson 1983 and Duffy *et al.* 1987 for analysing diet contents in pellets.) Stones are not picked up as artifacts because the items shags eat are not known to swallow stones (Cott 1961) and because, commonly moving food around in their beaks for easier swallowing, shags can discard pebbles. Moreover, none of the food samples that showed evidence of recent capture contained stones.

It is unlikely that stones are used to decrease buoyancy or to assist in swimming. Such functions for gastroliths clearly are important in crocodiles, where stone weights exceed 1% of the body weight in adults (Cott 1961, Darby & Ojakangan 1980). These reptiles, however, are "sit-and-wait" predators, remaining motionless on the bottom and capturing prey as it moves past. Shags are pursuit swimmers and may adjust buoyancy by several adaptations such as expelling air from the plumage. Furthermore, in shags average stone weights are too small to have a significant effect on swimming attitude.

Obtaining stones as a digestive adjunct is an active process in shags. The evidence here suggests that shags select stones during or after feeding, and commonly after consuming food with hard chitinous remains or with numerous bones. Other criteria obviously are important because most shags I collected had no stones. Field observations indicate that shags regurgitate stones and pellets before they go to feed (Duffy *et al.* 1987), often after uttering a distinctive call (Robertson & van Tets 1982, Siegel-Causey 1986a), but it is possible that they collect stones at other times. Van Tets (1968) saw a White-breasted Cormorant *Compsohalieus fuscescens* picking up small pebbles before flying out to sea from a beach, presumably to feed.

Gastroliths are common in many birds, primarily in granivorous and herbivorous birds (Farner 1960, Meinertzhagen 1964, Jenkinson & Mengel 1970), but there are few reports about their use in marine birds other than

in Phalacrocoracidae (see also Lewis 1929). This may indicate simply a lack of observations, or it may indicate a functional inability of this group in processing particular foods. It may also reflect the retention of a primitive trait found in crocodiles (and dinosaurs--see Darby & Okajangan 1980, Stokes 1987), but with a different function. Although the evidence is clear that gastroliths in crocodiles are primarily for reducing buoyancy, radiographic observations of gastroliths while crocodiles are feeding strongly suggest that they sometimes help break down large food items (A. W. Crompton, pers. comm. *in* Darby & Ojakangan 1980). It is plausible that stone-swallowing might have persisted in the basal groups of birds as a result of selection on the originally secondary digestive capacity of ballast stones.

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