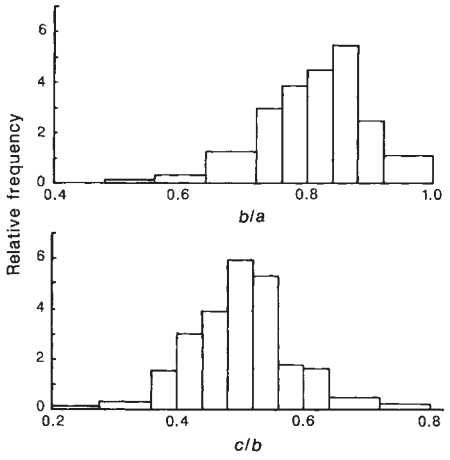
The form of pebbles

SIR—In admiring the beauty of pebbles on sea beaches, I have always suspected that they tend towards a specific form. Pebbles never approach the spherical, the two lesser dimensions never approach equality, and they are never very long (cigar-shaped). They are always somewhat flattened. The natural process of wear in the surf seems to tend to produce a certain proportion, but I have never heard of a study nor even a mention of this phenomenon. Unable to restrain my curiosity, I set out to ascertain the statistical distribution of the proportions of well-worn pebbles using a vernier caliper.

To be representative of the natural distribution, the pebbles must be randomly chosen. At the same time it is necessary to limit the choices to well-worn pebbles. I picked up samples from a large accumulation of pebbles with scarcely a glance, and examined each to see whether it could be considered 'well worn'. If a pebble was not roughly symmetrical with respect to three planes, I discarded it. Of those accepted, I measured and recorded the three principal dimensions. Designating the dimensions in order of decreasing magnitude *a*, *b* and *c*, I calculated *b*/*a* and *c*/*b*.



Nothing statistically significant can be concluded from the distribution of size, represented by the long dimension *a*, because natural transport of the pebbles along the beach by currents and by the surf results in segregation in different places by size. All the measured pebbles were between 3.2 and 12.6 cm long.

The figure shows histograms of the ratios *b*/*a* and *c*/*b* based on a sample of 200 pebbles. The mean values are $b/a=0.812$ and $c/b=0.503$. The peaks of the distributions seem to occur at about $b/a=0.86$ and $c/b=0.50$, and it is presumably to these values that the pebbles tend as they wear in the surf. Thus the ultimate stable configuration seems to be a flattened ovoid of the proportion 7:6:3 with symmetry about three perpendicular planes.

Why do pebbles tend to these proportions? The wearing process in the surf must be very complex, but somehow statistically regular. I suspect that pebbles tend not to roll at a constant angular velocity but, due to initial chance asymmetry, tend to flip. This must reinforce the inequality of the two lesser dimensions as they wear, tending eventually to produce a ratio $c/b=0.5$, which is relatively stable.

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Skua survival

SIR—Eppley and Rubega in their Scientific Correspondence[1] reported reproductive failure among South Polar skuas (*Catharacta maccormici*) nesting at Palmer Station, Antarctica, in 1988–89, and concluded that failure was an indirect effect of an oil spill from the Argentine ship *Bahia Paraiso*, which ran aground in January 1989. Although Eppley and Rubega reported no direct evidence of infection, fouling or toxicity to birds, and saw no oil on any adult birds, they nonetheless concluded that the failure must have been connected to the oil spill because of coincident timing of the two events. The authors also suggested that lapses in nest attendance, which they claimed were caused by adults attempting to clean oil from their plumage, led to the death of chicks. Here we suggest that these conclusions are incorrect.

We have studied skuas on King George Island (62°10′ S, 58°30′ W, 500 km northeast of Palmer station) for 10 years, and have just completed[2] a 23-year study of South Polar skuas at Cape Crozier, Antarctica (77°32′ S, 169°23′ W). This species also failed in 1988–89 at King George Island, where there was no oil spill; the third season they have failed during the course of our studies. Similarly, in two of the three years (1982–83 and 1988–89), skuas at Palmer also failed; for the third King George failure (1986–87), no Palmer data exist. In the more severe case of Cape Crozier, the species failed in four of every five years[2]. Breeding failure is thus hardly unprecedented for this species.

South Polar skuas coexist with the larger Brown skua (*C. lönnbergi*) at both King George and Palmer. Where sympatric, the dominant Brown skua feeds mostly on penguin eggs and chicks and the South Polar skua feeds at sea. Breeding success among South Polar skuas at King George and Palmer[3] was similar with a mean 0.70 and 0.62 chicks fledged per pair over 10 and 9 years, respectively. These datasets share five years in common, four of which are nearly identical, including the poor 1980–81 season, productive 1983–84 year and the 1982–83 and 1988–89 years of total failure. The fifth season (1977–78) differed because pesistent pack ice at Palmer[3] prevented male South Polar skuas from acquiring the food needed to bring females into egg-laying condition; that season there was no ice at King George.

Poor reproductive years differ in three ways from successful ones: few pairs attempt to breed; the proportion of 1-egg (as opposed to 2-egg) clutches is high; and the fish *Pleuragramma antarcticum* is rare or absent from the skua diet. In 1988–89 at King George Island, only 9 of 33 South Polar skua pairs attempted to breed; seven of these laid only one egg, and we observed no fish fed to females during the November courtship period nor to chicks before their deaths. Similar patterns existed during the unproductive season 1982–83 at King George. This contrasts with five successful seasons during the 1980s, when South Polars laid 2-egg clutches, averaged 1.25 fledglings per pair (range 1.0–1.55), saw about half of all pairs fledge two chicks, and typically allowed tens to hundreds of intact *Pleuragramma* to lie uneaten (as surplus) at their nests.

The breeding population at Palmer was censused during 1987–88, and 306 pairs bred on five islets[4]. In 1988–89, only 88 of these pairs bred, and 81 per cent laid only one egg. These results are nearly identical to King George data, where poor food, not oil, was responsible for the reproductive failure of South Polars.

Eppley and Rubega reported that nestlings grew normally during the spill, implying that food supply was not a factor, but presented no supporting data. They reported that adults' nest-attentiveness decreased following the spill, presumably to clean oiled plumage and suggested this caused the 1988–89 breeding failure. Adult skuas typically reduce time on territory as chicks age[5], a tendency exaggerated during food stress when chicks constantly approach to beg for more food. The parents' response is to leave in search of prey[5] (W.Z.T. and S.G.T., unpublished data). The chicks at King George Island all died between 25 January and 15 February 1989, coincident with the post-spill period at Palmer. We conclude that lack of food caused the breeding failure in 1989 at both King George and Palmer, without help from the oil spill.

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EPPLEY AND RUBEGA REPLY—Trivelpiece *et al.* contend that reproductive failure in skuas is expected whenever