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# Strategies of mussel dropping by Carrion Crows *Corvus c. corone*

J. D. WHITELEY, J.S. PRITCHARD *and* P.J.B. SLATER*
*Department of Biology and Preclinical Medicine, Bute Buildings, University of St Andrews, Fife KY16 9TS, UK*

*Carrion crows were observed dropping mussels on the mussel beds and sand of the Eden Estuary, Fife, and on the runway at the neighbouring Leuchars airfield. Crows tended to choose the largest mussels and to drop them on hard surfaces from heights which minimized the total climbing flight required to break them. They seldom gave up, in keeping with an experiment showing that the chance of a mussel breaking open does not change with the number of times it is dropped. While mussels are especially likely to break if dropped on harder surfaces, an advantage of dropping them on the mussel beds is that this may break other mussels as well as the one that is dropped.*

Both crows and gulls are known to break mollusc shells by dropping them from a height. There is also evidence that they choose an appropriate surface on which to do so. Barash, Donovan & Myrick[1] found that Glaucous-winged Gulls (*Larus glaucescens*) preferred to drop clam shells on hard surfaces, and the Kelp Gulls (*Larus dominicans*) studied by Siegfried[2] would often fly some distance to drop the mussels on which they fed onto hard flat surfaces. Zach[3,4] analysed the whelk-dropping behaviour of Northwestern Crows (*Corvus caurinus*) in terms of optimal foraging theory. He found that the birds preferred to drop larger whelks and, like gulls, tended to choose hard surfaces. The birds would drop the same shell repeatedly and would seldom give up if it did not break. Zach's results suggested that the height from which the whelks are dropped is close to that which would minimize the birds' energy expenditure.

Carrion Crows (*Corvus corone*) on the Eden Estuary in Fife, Scotland, also break shells, in this case mussels (*Mytilus edulis*), by dropping them from a height. Some birds carry mussels to the neighbouring airfield at Leuchars to drop them on the hard tarmac surfaces there. This paper concerns their behaviour. Do they choose a particular size of mussel? Do they prefer a hard surface? Is the height from which they drop such as to minimize their energy expenditure in breaking a shell? We will also present data on the breakability of mussels dropped onto different substrates from various heights.

## METHODS

Crows were observed on the Eden Estuary at low tide, when the mussel beds were exposed, between 1 February and 23 March 1988. Observation was from a range of some 350 m at a point where the whole mussel bed and the sand behind it could be observed, as well as departure of the birds towards the airfield, though not their behaviour once there. A 3-m pole, erected on the mussel bed, was used to allow estimation of dropping heights. This was done by taking a photograph from the observation point and using features of the landscape behind to mark it off in 1 m intervals. The point against this landscape from which dropping took place could then be used to assess height. In this way the approximate heights of drops that occurred up to 15 m above the ground and 30 m either side of the pole could be obtained. To ensure that a complete sequence was recorded, crows were only observed immediately after they had completed eating a mussel, or when they had newly arrived in the

*To whom correspondence should be addressed.

area. The numbers and heights of drops were recorded, as was the outcome of the sequence, which came into 4 categories: mussel lost; mussel eaten; mussel taken to airfield; crow gives up.

Mussel size was measured by taking the length of one of the valves at its longest point. This was done to a sample of shells taken from the beds at each of 4 points along a transect down the beach from high water (100, 200, 270 and 370 m). It was also done to mussel shells which were found on the airfield where at least one valve was unbroken so that measurement was possible. Unfortunately measurements of mussels dropped on the mussel bed or sand was not possible because there were many empty shells there and one could not be certain which had been dropped by crows.

The breakability of mussels of 3 different size ranges (small (30–45 mm), medium (50–65 mm) and large (70–85 mm)) was assessed by dropping a sample of each from a ladder onto 3 different substrates comparable to those used by the crows. These were: a concrete surface; a 8-cm deep tray filled with mud, live mussels and broken mussel shells; a 8-cm deep tray full of fine wet sand. These simulated the runway, the mussel bed and the beach, respectively. Ten of the largest sized mussels were dropped onto the tray of sand from 5 m. With the other 2 substrates, 10 mussels of each size classs were dropped from 1, 2, 3, 5 and 8 m. Each mussel was dropped 20 times or until it broke. A mussel was scored as broken if either valve was broken or if they could be slid apart to reveal a gap of 2 mm or more. The latter criterion was used as many opened mussel shells on the runway were found to have both valves intact.

## RESULTS

### Dropping behaviour

Crows often spent several minutes (mean = 5.1, se = 1.0, $n$ = 23) searching for and selecting a mussel to drop. Having chosen one they commenced dropping at once, flying up almost vertically and usually dropping the mussel at the highest point. Sometimes they lost height and hovered just before releasing the mussel, perhaps to help fixate the point where it landed (see Ref. 2). After dropping they would descend quickly but would slow down before landing, probably to position themselves close to the dropped shell.

Time from the first drop to the point when the crow started eating the mussel was measured for several sequences. The mean time was 2.3 min (se = 0.35, $n$ = 10) and the mean time spent eating was 2.6 min (se = 0.3, $n$ = 22). Thus the total time from starting to look for a mussel to the end of eating, for successful sequences, was around 10 min. Of 44 crows watched on the mussel bed, 28 succeeded in breaking their mussels, 11 moved with their prey to the runway, 3 failed to retrieve their mussels after dropping them and 2 gave up after a number of drops. It was thus rare for crows to give up. The maximum number of drops observed with the same mussel was 17. It appeared that individuals tended to use particular drop heights but, without marked birds, it was not possible to confirm this. There was a slight tendency for drop height to increase as the series progressed, but this was not significant.

Of 11 birds seen to take their mussel to the runway 4 had previously dropped the same mussel on the mussel bed. One was seen to drop its mussel 16 times unsuccessfully before moving to the airfield.

### Shell size selection

Mussel shells found on the airfield averaged 67.7 mm in length (s.e. = 0.32, $n$ = 280) (see Fig. 1). None of the mussels at the three sampling sites highest on the beach were as large as

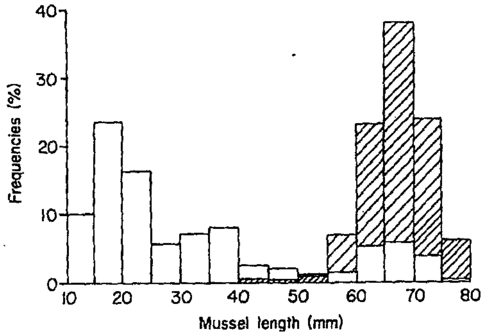


**Figure 1.** Histogram showing the size distribution of mussel shells in the mussel bed 370 m down the beach (□) and that of shells that had been dropped on the runway by crows (▨).

this, but a proportion of those at the lowest site (370 m down) were that large, and this was also the area in which the crows were seen to feed on almost all observations on the mussel beds. On only 2 occasions was a crow seen feeding as high as the 270 m site. However, even at the 370 m level on the shore, many of the mussels were smaller than this; these were apparently ignored by the crows.

## Mussel breakability

### *Effect of mussel size*

A total of 50 mussels of each size class was dropped from the 5 different heights onto concrete. The mean number of drops required to break them was greatest in the case of the small mussels, and slightly higher with the medium ones than with the large. All shells dropped from 8 m broke the first time regardless of their size. For other dropping heights combined, on the first drop breaking occurred in 67.5% of large shells, 62.5% of medium ones and only 32.5% of small ones ($n = 40$ for each size).

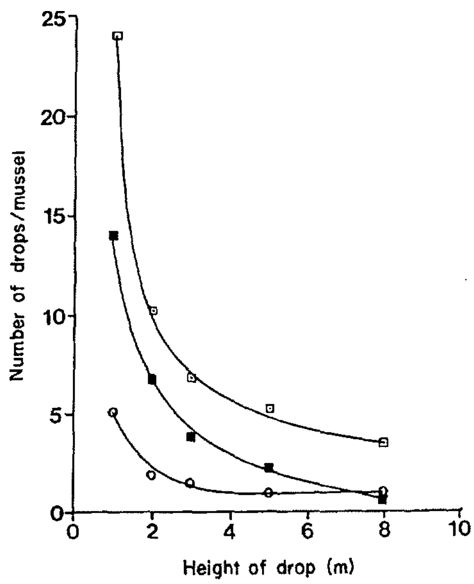


**Figure 2.** The effect of the substrate on the durability of medium and large mussels (50–85 mm). The plots show the mean number of drops from various heights required to break a mussel dropped onto concrete (○) and onto a tray of sand and mussels (□). The third plot (■) is also for the mussel tray but includes mussels that were broken as a result of dropping other mussels upon them. Curves fitted by eye.

### *Effect of substrate*

Dropping mussels onto the simulated mussel bed sometimes led one of the mussels in the tray to break as well as the one being dropped. Such a result may explain why crows on the mussel beds sometimes appeared to stop and eat before continuing to drop the same mussel again.

Figure 2 shows the effect of substrate on the durability of mussels, combining data from the 10 individuals of the 2 larger size-classes dropped from a particular height. These 2 size-classes are closest to that of mussels taken to the runway. Mussels dropped on concrete required, on average, fewer drops to break than those dropped on the tray of mud and mussels. However, when mussels breaking as a result of crows dropping other mussels upon them were included in the latter category, the difference between results is not so strong. After each drop those mussels in the tray which broke (sometimes as many as 3 or 4) were counted and replaced by intact ones. As a result of these incidental breaks, with drops from 8 m the mean number of drops per mussel broken actually falls to below one. However, the density of live mussels in the tray was considerably higher than that in the field, where the beds contain many empty shells, so the success of crows dropping on the mussel beds is unlikely to be so great.

Dropping mussels on sand is clearly less successful: of the 10 large individuals dropped 20 times onto the sand tray from 5 m, only 2 broke.

### *Dropping heights*

As might be expected, and as Fig. 2 shows, the higher the drop, the more likely it is that the mussel will break. However, rather than flying to a maximum height each time, crows might be expected to minimize the total upward flight necessary to break a shell.[4] Combining the large and medium categories, to give a size range similar to that dropped by the crows on the runway, Fig. 3 shows the total height for

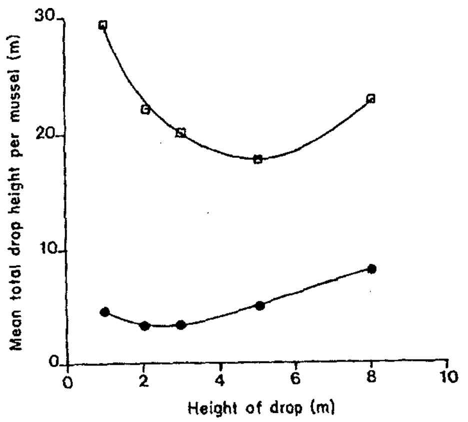


**Figure 3.** The mean total drop height required to break a mussel dropped on concrete (●) and on the mussel tray (□), when they were dropped repeatedly from various different heights. Total drop height is arrived at by adding up all the heights from which a particular mussel was dropped. Crows could minimize the total distance they had to climb above a particular substrate by using the drop height at the lowest point on each curve. Curves fitted by eye.

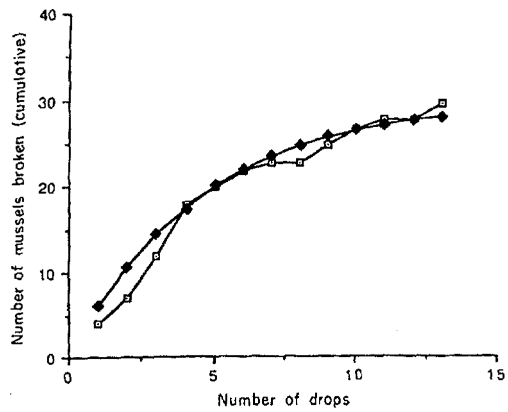


**Figure 4.** A cumulative plot of the number of mussels, out of a total of 30, that had broken at each point through a series of drops from 1 m (□). The most durable mussel broke after 13 drops. The other plot (◆) shows the distribution that would be expected if the probability of a mussel breaking did not depend on how many times it had previously been dropped.

which shells had to be dropped before breaking (all the dropping heights added up). The 2 plots do suggest that dropping from an intermediate height (2.5 m on concrete) 5 m on the mussel tray) would be optimal. Given the low number of breaks amongst shells dropped from 5 m onto sand, an even higher dropping height would be expected for that substrate.

No measures could be made of the actual dropping height used by crows on the runway, but it is estimated at around 2–3 m (J.S. Pritchard, pers. obs.). On the mussel bed the mean was 4.3 m (se = 0.12, $n$ = 266), and on sand it was 5.1 m (se = 0.35, $n$ = 81), this difference being significant ($t$-test, $P < 0.001$). The observed dropping heights were thus in line with expectations from the experiments.

One factor which may affect the dropping heights of crows is the presence of other individuals nearby, as they often steal shells from each other. To test this the drop heights of birds on their own (mean = 4.6 m, se = 0.18, $n$ = 111) were compared with those when there were at least 5 birds (crows and/or gulls) within 8 m of the dropping crow (mean = 2.2 m, se = 0.17, $n$ = 77). The difference was highly significant ($t$-test, $P$ = 0.008).

*Sequences of drops*

The best dropping strategy for a crow will depend on whether the chance of a mussel breaking changes with the number of times it is dropped. Some mussels may be very resilient and so unlikely to break at all if they survive the first few drops. Alternatively, successive drops may weaken the mussel so that it becomes more likely to break. If the former were true we might expect crows to give up after a few unsuccessful drops. On the other hand, if dropping weakens the shell, we would expect the crows to persist until the shell breaks.

Data for all mussel sizes dropped from 1 m onto the concrete were combined to test this idea. The number that had broken at each point in the sequence of drops is shown in Fig. 4, compared with that expected if the probability of breaking was constant. The 2 distributions are closely similar ($\chi^2$ = 15.96, df = 12, ns). Thus the chance of a shell breaking does not seem to alter with the number of drops.

## DISCUSSION

It has often been suggested that animals foraging efficiently should maximize their net energy gain per unit time spent foraging.[5] Net energy gain is the difference between intake and expenditure. To what extent do crows do this?

To maximize energy gain, crows should choose large mussels. As the energy content of mussels is proportional to the cube of their length[6] larger mussels are also disproportionately productive. Furthermore, as shown above, they break more easily. Thus it is not surprising that crows tend to take large mussels. It may be more curious that the mussel sizes taken range over 30 mm. A possible reason for this may be that very large mussels are scarce so that the foraging time required to locate one counteracts the gain to the crow once it has done so. It might, for example, be able to eat several medium sized mussels in the same period.

As far as substrate is concerned, sand was found to be the least effective and, as expected, crows were seldom seen to drop mussels on sand. Concrete, simulating the hard runway, was very much better than the tray of mud and mussels. Taking the minimum points of the 2 curves in Fig. 3 suggests that breaking on concrete requires a mean total height of at least 3.3 m while breaking on the tray of shells and mud requires 17.6 m. However, the difference in productivity will not be as great as these figures suggest because of incidental breaks of shells on the mussel beds. Nevertheless, dropping on the runway is likely to have a higher yield, as the crows' behaviour suggests. Birds flying there are also less likely to suffer from kleptoparasitism, and will certainly find it easier to retrieve their shells after dropping them than on the mussel beds. Set against these advantages is the cost of a round trip to the runway from the mussel beds of around 1070 m.

Some preliminary calculations can be used to put these arguments on a sounder footing. The minimum power speed for a crow is probably around 40 k.p.h,[7] giving a time of about 180 s for the round trip to the runway. Figures for similar North American crows suggest that flight costs would be around 28 J/s,[8] so that the whole trip would cost in the region of 5 kJ. Elner & Hughes[6] give the energy content of a 65 mm mussel as about 28 kJ, of which one might expect around 80% to be assimilated,[9] giving a yield of 22.4 kJ. Even these very rough calculations, therefore, suggest that the energy spent on the flight to the runway is more than replaced by the yield from the mussel. However, this takes no account of the fact that the time spent in the operation might have been devoted to searching for other food on the seashore which yielded a higher net gain.

The drop heights used by the crows were approximately in accord with those predicted from our experiments if they were attempting to minimize ascending flight. This agrees with the conclusion of Zach[4] in his study of whelk dropping by Northwestern Crows. If anything, Carrion Crows drop shells from rather lower than expected. This could be accounted for by the problem that they sometimes had in locating the shell they had dropped. Some 6.8% of sequences ended with the shell being lost, and this is likely to be related to dropping height. Furthermore, the higher the drop, the more time the mussel is unguarded and the more scope there is for other individuals to steal it. In keeping with this, drops were found to be lower when other individuals were in the neighbourhood of the dropping bird.

Finally, the observation that crows rarely give up even if they have dropped their mussel many times without it breaking is consistent with the experimental finding that the probability of a mussel breaking does not change with successive drops. While persistence does not yield great rewards, there is no benefit in giving up after a number of unsuccessful drops. Indeed, remembering that a bird which gives up is likely to take several minutes to find another shell, one would expect persistence to be the best strategy. The many drops shown by some crows suggest that this is what they do.

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