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Hand-reared common swifts (*Apus apus*) in a wildlife rehabilitation centre: assessment of growth rates using different diets

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Abstract

Common swift (*Apus apus*) orphans represent an important number of admissions to wildlife rehabilitation centres in Europe. Rehabilitation centres may encounter difficulties in the hand-rearing of large numbers of insectivore chicks if they use commercially available insects, which are usually expensive and nutritionally incomplete. These constraints have created the necessity for alternative diets; however, these may not be optimal for hand-rearing purely insectivorous species. In this study, 116 orphan common swift nestlings were hand-reared during June and July 2008 and 2009 in the Torreferrusa Wildlife Rehabilitation Centre (Catalonia, northern Spain). We assessed growth rates and final fledgling weight under four different diets, comparing the results to those of wild parent-raised common swifts. Clinical condition at admission was the main variable predicted to influence the results. The four diets were (1) rat mince diet, a specific pathogen-free laboratory rat mince; (2) kibble diet, a formula based on a high-protein–low-carbohydrate cat food; (3) cricket diet, based on house crickets (*Acheta domesticus*) and wax moth larvae (*Galleria mellonella*); and (4) mealworm diet, based on mealworm larvae (*Tenebrio molitor*). Reference adult weights of wild animals were obtained from the literature (41.5g ± 2.42 SD). The results showed significant differences in final weights, which were considerably lower for hand-reared animals on the non-insect diets (rat mince diet: 32.8g ± 2.7; kibble diet: 32.5g ± 3.7). The final weights in both insect diet groups were satisfactory, with values close to those observed in the wild (cricket diet: 40.1g ± 4.0; mealworm diet: 40.3g ± 3.1). The results of this research highlight the need to implement changes in diet protocols when using non-insect-based diets.

Introduction

Many orphaned birds are transferred to wildlife rehabilitation centres for attention every year. Common swift (*Apus apus*) orphans represent an important number of admissions in rehabilitation centres in Europe. In 2009, Torreferrusa Wildlife Rehabilitation Centre (Catalonia, northern Spain) received 712 young common swifts. As an altricial species, both nestlings and fledglings are dependent on their parents, thus requiring hand-rearing for survival.

The common swift is a migrant insectivorous apodiform bird that spends most of its life on the wing. It is monogamous and commonly nests colonially in urban areas. The breeding biology of common swifts differs from passerine birds of similar size: it has a smaller clutch size; a rather longer incubation and a much longer nestling period; a greater ability to withstand starvation; and a capacity to retard its growth and become poikilothermic when undernourished, and to recover rapidly when conditions improve (Lack 1956; Bernis 1980; O'Connor 1984). The growth curve may be interrupted by sharp drops in weight with poor weather (cold, rainy or windy conditions), when food is scarce. This may affect development; however, brood reduction mostly compensates for these effects, and usually growth rates and fledging weights are not markedly affected in the remaining surviving nestlings (Lack and Lack 1951; Martins and Wright 1993a, b; Martins 1997).

In common swifts, several reasons why nestlings fall out of the nest have been suggested. Accidental causes include parents or siblings pushing the young unintentionally, young suffering in the heat and scrambling to the entrance (Lack 1956), or young jostling for a position near the entrance to monopolise parental attention (Bize and Roulin 2006). Other losses can be attributed to sibling competition and brood reduction. This is a strategy where parents may induce selective removal of the weakest offspring in an attempt to assure breeding success when food is scarce (O'Connor 1979; Martins and Wright 1994; Cucco and Malacarne 1996), with a parental preference for larger (Lotem 1997) or more actively begging nestlings (Leonard et al. 2000).

Wildlife rehabilitation practice guidelines suggest body weight and plumage condition as essential indicators of individual chances of survival to release (Stocker 2000; MacLeod and Perlman 2001; Best and Mullineaux 2003). Low fledgling body weight can lead to low fitness, and thus decreased chances of survival (Perrins 1965; Johnston 1993; Klasing 1998; Schauroth and Becker 2008). Common swifts need to be in exceptional body condition at fledging, with strong flying abilities and therefore a large pectoral mass (O'Connor 1984). Apparently young spend the first night after fledging on the wing (Lack 1956; Tarbuton and Kaiser 2001), and may start on migration shortly after leaving the nest, a long journey crossing the Sahara to their wintering grounds in Africa (Koskimies 1950; Brown and Grice 2005), flying at high altitudes, often above 2000 m (Gustafson et al. 1985; Chantler 2000). Common swifts need to be able to execute fast movements, flying without rest and usually at high altitudes with low oxygen pressure, which involves tremendous energy expenditure (Palomeque et al. 1980). A reduction in body weight slows down flight speed (Martins 1997) and can have negative repercussions for migration as the distance it is possible to travel can be diminished (Alerstam and Lindström 1990) and predation risk can increase (Lima 1986). Dull plumage, which may consist of severely malformed feathers, cannot supply flight performance, insulation or waterproofing. None of these factors – reduced growth, low body weight or poor feather condition – seem compatible with survival in the wild.

The conditions under which birds are maintained while in captivity, their diet and the amount of parental care received have profound influences on the health, growth and development of nestlings (O'Connor 1984; Flammer and Clubb 1999). Husbandry management should aim to simulate conditions in the wild. With diet an essential factor, nestlings in captivity should be fed the same foods the parents would have fed them with in the wild; however, duplicating this is a challenging task. Wildlife rehabilitation centres dealing with insectivorous species may encounter difficulties in the hand-rearing of large numbers of chicks, as there is a limited selection of commercially available insects (and they tend to be expensive). Even when it is possible to use insects to feed insectivores, the diet is often limited to a single insect species. The nutritional composition of commercially produced insects has been studied, and may be incomplete in terms of minerals and other nutrients without appropriate supplementation (Bernard and Allen 1997; Barker et al. 1998; Finke 2002; Finke and Winn 2004). Cost is usually the limiting factor in using insects; it is an important constraint that has created the necessity for using alternative diets, which also take effort and accessibility into account. The formulation of a diet is complex; a balanced diet requires the precise combination of 45 different nutrients (chemical elements and compounds), and a large number of nutrient interactions needs to be evaluated, considering the differing bioavailabilities of these nutrients from different ingredients (Brue 1999). Dietary formulae where the main components are not insects or are combined with insects have been developed, with good results in nestling passerines (MacLeod and Perlman 2001; Winn 2002), and some authors have stated that some of these diets can be used as stand-alone insect substitutes (Winn and Finke 2008).

Avian insectivores, particularly aerial feeders, consume a huge diversity of invertebrate species (Lack and Owen 1955; Bernis 1987), the combination of which, along with the intestinal content of the prey (Hernandez-Divers 2006), presumably supplies a complete diet. Like common swifts, almost all altricial passerine parents feed their young insects, regardless of the adult's diet (O'Connor 1978, 1984; MacLeod and Perlman 2001).

The aim of this research was therefore to investigate growth rates in hand-reared common swifts fed different diets and compare them to those of wild birds. Clinical condition at admission was the main variable predicted to influence final fledging weight.

Table 1. Number of feeds per day and amount supplied for the four diet groups.

	Approximate daily amount (g)			
Age (days)	Rat (5 feeds)	Kibble (8 feeds)	Cricket (5 feeds)	Mealworm (5 feeds)
10–20	18	14	20	20
21–30	15	14	20	20
30–release	10	14	15	15

Methods

Experimental work was carried out in June and July of 2008 and 2009 in the Torreferrusa Wildlife Rehabilitation Centre. We divided 116 common swift nestling orphans into four different diet groups (two insect and two non-insect diets).

Diets

Diet 1: rat meat. A rat mince diet was used in Torreferrusa Wildlife Rehabilitation Centre until 2008. It consisted of specific pathogen-free laboratory rat, without skin and bowels, minced with the flesh and bones. The rat mince was supplemented with multivitamins, mineral and aminoacids added to the drinking water (Nekton S®, Nekton Produkte, Germany). Rat mince was administered in the form of small balls, with a few drops of water given afterwards to facilitate swallowing.

Diet 2: kibble. This diet formula was based on the formula for nestling songbirds (FoNS©) (Winn and Finke 2008), substituting the original Evo® dry cat and kitten food (Natura Pet Products Inc., USA), which was not available on the European market, with Orijen® (Champions Petfoods Ltd, Canada). The formula also included dried egg white, active-culture plain yogurt and vitamins (Avi-Era™, Lafeber Company, USA). The dry components were pre-soaked in water and blended in a food processor. The mixture, with a cream-yogurt like texture, was administered by syringe tip deep into the oesophagus.

Diet 3: cricket. The cricket diet is used in the Mauersegler Klinik (Frankfurt, Germany), a rehabilitation centre specialising in common swifts (Haupt 2009). It was composed of 90% house crickets (*Acheta domesticus*) and 10% wax moth larvae (*Galleria mellonella*). The insects were 200–300 mm in length. Insects were frozen alive straight from the supplier and thawed before feeding. For one feed a day, the insects were dusted with a vitamin and mineral supplement (Korvimin ZVT®, Firma WDT, Germany). Entire insects, including legs, were administered using rounded-end tweezers.

Diet 4: mealworm. The mealworm diet was based on the formula used to hand-rear chimney swifts (*Chaetura pelagica*) in the USA by Kyle and Kyle (2007). It was composed entirely of mealworms (*Tenebrio molitor*) varying from 100 to 300 mm in length. Larvae were kept at 5^{o} C on a wheat bran substrate. On alternate days the mealworms were either soaked alive in a supplement mixture dissolved in water (Sera Mineral Plus V®, Sera, Germany; Avi-Era™), or soaked just in water and at one feed dusted with supplements

Table 2. Definitions of clinical conditions used in Torreferrussa Wildlife Rehabilitation Centre protocols for orphan birds, and number of animals that completed hand-rearing in each sample group. Survival under non-insect diets has proved very low and will be analysed further (Fusté, in preparation). Data from young common swifts that did not complete the hand-rearing process were omitted from the samples.

Clinical condition	Body condition	Other clinical signs	Rat *n*=34	Cricket *n*=29	Mealworm *n*=28	Kibble *n*=25
1	Apparently normal		4	4	2	9
2	Weight loss	Slight dehydration	18	7	5	5
3	Emaciation	Severe dehydration, weakness	12**	7	9	9*
4	Severe emaciation	Severe dehydration, severe haemorrhage, shock	0**	11	12	2*

** Four birds from the Rat mince group in clinical condition 4 and two in clinical condition 3 died a few days after admission. * Five birds from the Kibble group in clinical condition 4 and three in clinical condition 3 were moved to insect diets to avoid risk of death once poor progress was observed.

(Korvimin ZVT®) and nutritional yeast (Marigold Engevita®, DSM Food Specialties, Netherlands). Insects were administered using rounded-end tweezers.

In addition to the supplementation, vitamin B complex (Complejo B8 Inyectable®, Laboratorios Calier SA, Spain) was administered subcutaneously in the inguinal fold every 10 days in both insect diet groups.

Food intakes were closely related to the begging behaviour of the chicks. Feeding amounts for each diet are summarised in Table 1.

Admission and housing protocol

All nestlings received a physical examination upon arrival and were identified with a numbered ring. Initial care and stabilisation consisted of oral fluid therapy in the non-insect diet groups (Glucolyte®, B. Braun VetCare SA, Spain) and subcutaneous fluids in the inguinal fold on the insect diet groups (Lactate's Ringers Solution®, B. Braun VetCare SA, Spain). Because cestode parasitism is a common finding in common swifts, all birds were treated with an antiparasitic drug, praziquantel, at a dose of 10mg/kg (Droncit®, Bayer AG, Germany). Three birds were housed in each plastic container, with absorbent paper as a substrate, which was changed after each feed. Young were considered ready for release when all primaries were sheathed and the wing length was about 165 mm, extending at least 35 mm beyond the tail feathers. Fledglings were released during the afternoon in areas with some height up off the ground and an abundance of other wild common swifts.

Sample groups

Sample groups were distributed among the different diets, and classified by clinical condition, a number ranging from 1 to 4 as defined in Table 2. Maximum age for sample nestlings was 24 days. Age was estimated by comparing the new arrivals to a set of photographs of the age-specific developmental sequence of well-fed wild nestlings, taking into consideration feather growth characteristics (Jongsomjit et al. 2007; Tigges 2008). Prior to the first daily feed (0800), nestlings were weighed to the nearest 0.1g with an electronic scale (MS500). Plumage condition was assessed during the hand-rearing process, paying special attention to feather loss, fault-bars, feather dirtiness and broken quills.

Body weights at fledging are normally higher than average adult weights (Lack and Lack 1951; Gladwin and Nau 1964; Collins and Bull 1996; Cramp 1998; Chantler 2000). For the purposes of this study, a sample obtained by Gadwin and Nau (1964) in the UK was used as a final body weight reference: *n* = 208, body weight = 41.5g (range 36.3–49.4, SD ±2.42); these final weights are similar to those observed by Lack and Lack (1951) in the UK and Rodriguez-Teijeiro (1980) in Spain (Table 3).

Internal organ evaluation

In order to evaluate the suitability of the mealworm diet further, three animals that received this diet for 20 days were selected for biochemical and histopathological studies. The birds were not releasable due to poor feather condition at admission.

Blood samples were collected from the right jugular vein and placed in serum separating tubes for biochemical analysis. Total protein, uric acid, calcium, phosphorus, aspartate aminotransferase (AST), bile acids, creatine kinase (CK), total cholesterol and HDL cholesterol were determined. Animals were humanely euthanased and a complete postmortem investigation was performed immediately.

Statistical tests were conducted using R software, version 2.11.1.

Table 3. Common swift body weights in different locations.

Reference	Location	N	Mean weight (g) (range)
Fledglings			
Weitnauer (1947)	Switzerland	30	53.5 (48.0–56.0)
Lack and Lack (1951)	UK	73	41.4 (34.0–52.0)
Rodriguez-Teijeiro (1980)	Spain	30	41.4 (34.5–51.5)
Pellantová (1981)	Czech Republic	31	Not given (45.6–49.5)
Bernis (1987)	Spain	14	Not given (43.0–52.0)
Pellinger (2006)	Hungary	16	53.6 (Not given)
Adults			
Lack and Lack (1951)	UK	102	42.7 (35.9–52.2)
Cramp (1998)	Gibraltar	24	44.9 (Not given)
Pellinger (2006)	Hungary	15	48.4 (Not given)

Table 4. Final fledgling weight and other variables, expressed as mean (range) ±SD.

Sample group	Fledging weight (g)	Admission weight (g)	Weight increase (g)	Estimated age at admission	Days of hand-rearing
Rat diet	32.8 (26.0–36.4) ±2.7	27.8 (21.5–41.3) ±4.9	4.9 (–7.0–11.5) ±4.6	17.0 (10.0–23.0) ±3.8	23.0 (17.0–30.0) ±3.8
Kibble diet	32.5 (27.5–38.0) ±3.7	36.2 (22.8–52.8) ±8.3	-3.8 (-16.0–10.0) ±6.5	18.8 (10.0–24.0) ±0.4	21.3 (16.0–30.0) ±4.0
Cricket diet	40.1 (33.5–48.7) ±4.0	26.8 (17.0–42.0) ±7.0	13.3 (-6.3–26.0) ±7.8	17.1 (10.0–23.0) ±4.0	23.9 (17.0–30.0) ±4.8
Mealworm diet	40.3 (33.0– 46.5) ±3.1	27.0 (11.9–37.8) ±5.9	13.3 (-2.7–25.9) ±6.2	16.8 (9.0–22.0) ±3.6	23.2 (18.0–31.0) ±3.6

Results

Fledging weight

The target variable was the difference between the final weight of hand-reared fledglings (Table 4) and the weight reference (41.5g) for a wild parent-raised fledgling. A two-way analysis of variance (ANOVA) was performed, with two factors: diet (four levels: Rat mince diet, Kibble diet, Cricket diet and Mealworm diet) and clinical condition at admission (three levels: clinical condition 1, clinical condition 2 and clinical conditions 3+4). Clinical conditions 3 and 4 were grouped as birds of clinical condition 4 did not complete the hand-rearing process on the two non-insect diets. Interactions between diet and clinical group were insignificant (F=0.659, df=109,103, p=0.683) when comparing both models. However, clinical condition groups and diet groups were found to be highly significant (F = 74.09, df = 6,109, p < 0.0001, adjusted R^2 = 0.79) (Table 5). The cricket and mealworm diets produced similar results and final weights for both were comparable to those observed in the wild. The non-insect diets were generally inferior, fledglings having a final weight 7 g below the wild reference weight. Clinical condition had some effect on final weight, but this was substantially smaller than the effect of diet. There were no significant differences in the effect of diet in the clinical condition groups, with parallel effects in the three conditions (Fig. 1).

A t-test with a Welch correction for unequal variances was conducted to compare the final weights of birds in two groups: 13 apparently normal young (clinical condition 1) from both non-insect diets (*n* = 4 on the rat mince diet, *n* = 49 on the kibble diet) and 23 birds with severe emaciation (clinical condition 4) on both insect diets (*n* = 411 on the cricket diet, *n* = 412 on the mealworm diet). The means of 34.87g and 39.71g, respectively, for these two groups were highly significantly different (t = -4.05, df = 24.88, p=0.0004). This result is notable, as even though we compared the worst cases in the insect groups with the best in the non-insect groups, the insect group nevertheless achieved the better result.

Table 5. The estimated coefficients for the different diet groups, reflecting variation with respect to the wild weight reference. Estimates by clinical condition reflect results for clinical condition 2 and clinical conditions 3+4 with respect to clinical condition 1, which was considered the reference value.

Group	Estimate coefficient	Standard error	t	p
Cricket diet	0.5629	0.966	0.583	0.5613
Kibble diet	-7.5817	0.8845	-8.572	7.55e-14 **
Mealworm diet	0.9961	1.0231	0.974	0.3324
Rat mince diet	-7.1975	0.9628	-7.476	2.05e-11 **
Clinical condition 2 (all diet groups)	-1.1702	0.9871	-1.186	0.2384
Clinical condition 3+4 (all diet groups)	-2.6352	0.9083	-2.901	0.0045 *

**p < 0.0001; *p < 0.001

Internal organ evaluation

The lack of reference values in the literature for common swifts made the interpretation of the results difficult. The results seemed to be within the normal range despite the fact that cholesterol levels were high in all animals (591, 517 and 640 mg/dL) compared

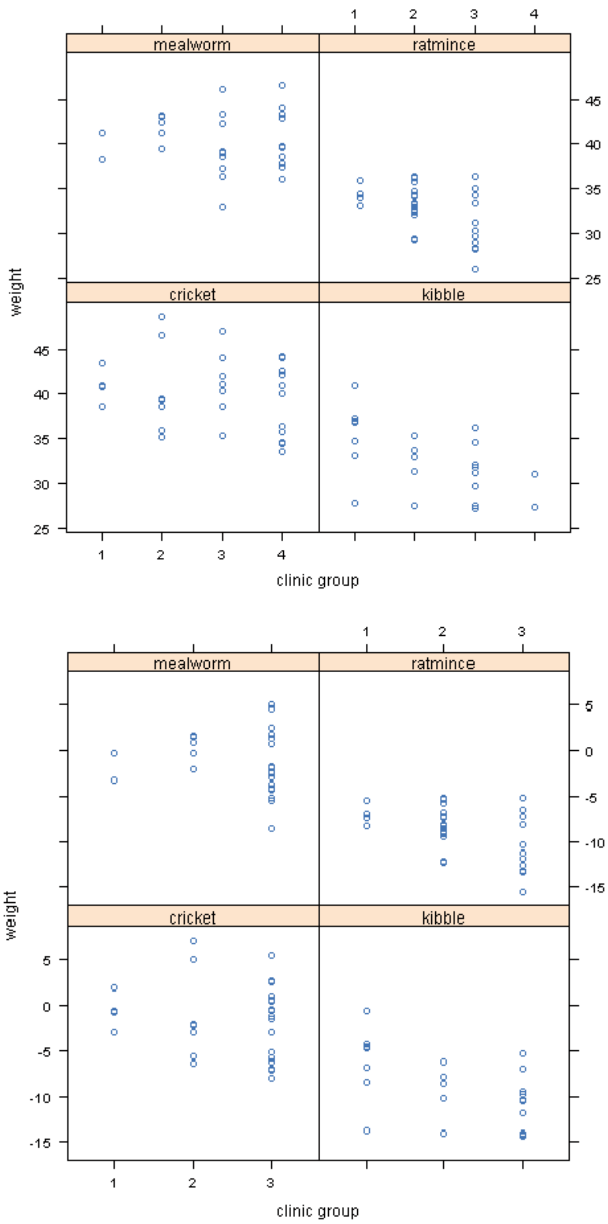

Figure 1. Top: All diet groups and clinical conditions (clinic group) with final weights presented as absolute values. Bottom: The four diet groups and clinical conditions (3+4 grouped into clinic group 3) with weight scales presented as differences compared to the wild reference weight (41.5g).

to reference values for other species. Histopathological studies revealed no lesions in any tissues analysed, which included liver, spleen, kidney, proventriculus, gizzard, duodenum, pancreas, lungs, heart, adrenal gland, ovary and oviduct.

Discussion

The results of this study draw the practice of hand-rearing common swifts with non-insect diets into question; weights of fledglings on insect diets showed a much greater similarity to weights attained in the wild. In interpreting the results, it is important to take into account the reasons for which orphans came to the rehabilitation centre and their recovery options. Clinical conditions 1 and 2 could have represented simply undernourished young, good candidates to recover weight rapidly: possibly nestlings that fell off the nest accidentally in good condition and endured a short period without food. On the other hand, young in clinical conditions 3 and 4 may have suffered sibling competition and been ejected from the nest, resulting in starving, emaciated nestlings (Martins and Wright 1993a). It was assumed that such emaciated birds, which would have endured a critical fasting period, were poor candidates for recovery. The results in both insect diet groups, however, showed optimal final weights in all clinical conditions, even in severely emaciated birds. Conversely, in both non-insect diet groups even the good candidates performed poorly. In addition, many birds in extreme clinical conditions (3 and 4) on the non-insect diet did not complete the hand-rearing process (i.e. they died or were moved to an insect diet), whereas on insect diets, the survival rate was high (Fusté, in preparation).

A compensatory strategy observed in common swifts, where individuals that have suffered retarded growth enter a phase of growth acceleration when conditions improve (Metcalfe and Monaghan 2001), was observed only in the insect diet groups. When individuals are unable to undergo compensatory growth, they become stunted, with a smaller body weight and size (Bize et al. 2003). Thus we have shown that the poor growth observed in the non-insect diet groups was related specifically to the diet: almost all birds on a non-insect diet had a stunted appearance when compared to their conspecifics on the insect diet groups.

Low body weight or poor growth may be caused by any factor that interferes with the homoeostasis of the nestling: improper feeding (insufficient energy, unbalanced nutrition or inappropriate diet), poor environmental conditions in early development or subclinical diseases that cause the nestling to expend energy fighting the disease instead of using it for growth (O'Connor 1984; Macwhirter 1999; Flammer and Clubb 1999). Nestling nutrition is the most obvious mechanism that may influence growth and body size (Ricklefs 1979; Johnston 1993), and it is a major factor in the husbandry management of any species (Best and Mullineaux 2003). This is particularly true of nestlings, as growth is the period during which most nutrients need to be at their maximum levels (Brue 1999). In young altricial nestlings, the energetic cost of growth is often more than 50 per cent of the daily metabolisable energy requirements (Bryant and Gardiner 1979; O'Connor 1984).

Birds are very sensitive to acute deficiencies in some nutrients (Klasing 1998; Brue 1999). The non-insect hand-reared groups, with the poorest growth rates, were fed on a diet that differed significantly from their natural food. The nutritional status of a growing bird is based on its ability to assimilate and metabolise the food supplied (O'Connor 1984). Insectivores, like other faunivorous birds, rely on a very competent digestive enzymatic capacity. Animal food prey is high in protein with a balance of essential amino acids similar to the bird's requirements (Klasing 1998). In terms of nutritional components, insects are high in proteins and lipids, with the amino acid balance almost as good as vertebrate prey, with good sources of phosphorus, vitamins and trace minerals, but low in calcium (Finke 2002; Hernandez-Divers 2006).

The rat mince diet and kibble diet were complete in terms of macro-nutrients, with protein and lipid contents similar to those observed in crickets and mealworms. However, nutritional strategies determine the types of food that may be consumed without digestive or metabolic complications: species are adapted to foods that are attainable and can be metabolised appropriately by an adapted digestive tract (Snyder and Terry 1986). Insectivorous birds have a moderate rate of passage, with an efficiency of digestion that approaches 100 per cent of the non-chitin components of insects. On the other hand, carnivorous birds have a slow rate of passage, an adaptation to efficient digestion of vertebrate prey (Klasing 1998). Common swifts fed on a carnivorous diet may therefore have less opportunity to assimilate and metabolise the food completely. A theoretically balanced diet may also appear to have all the required nutrients, but in fact be nutritionally inadequate due to the interaction of specific nutrients. This imbalance may be caused by excess of one nutrient impairing the metabolism of another functionally similar nutrient, causing a decrease in its absorption or increasing its catabolism or excretion (Klasing 1998; Brue 1999).

MacLeod and Perlman (2001) reported observations on nestling passerines fed commercial dog food. Birds matured at a slower rate than in the wild, they were stunted, and the plumage was not glossy and keratinised as in their wild conspecifics at the same age. In the present study, rat mince produced poor plumage and caused dirtiness on feathers, and thus many birds required a bath during the hand-rearing process. Flight performance at release, assessed in subjective terms by observation, was questionable (very few birds in the rat mince group managed to fly high). Plumage condition on the kibble diet was more acceptable, as was flight performance. Numerous birds on both non-insect diet groups, particularly on the rat mince diet, had retained feather sheaths during the hand-rearing process and needed manual preening. Even with this, fault-bars at the spot where the sheath constricted the feather left a weakened structure. In the insect diet groups, feather condition and flight performance was optimal when compared to those wild fledglings arriving at the rehabilitation centre and released the same day.

Nestlings show a form of sigmoidal growth (Ricklefs 1968); initially weight increases gradually, then speeds up, reaching a peak of 20–30% over the average adult, and finally falls again, with asymptotes that tend to exceed or be similar to adult weights (Lack and Lack 1951; O'Connor 1984). Birds rely on two major sources of energy, lipids from fat stores and proteins (O'Connor 1977; 1984). If they do not have enough lipids, they may start protein catabolism at a stage when proteins are fundamental for the development of vital organs and muscles (Ricklefs 1979). Adipose tissue was not observed in the non-insect diet group during development, in contrast to the birds in both insect diet groups. Fat deposits are important to avoid the formation of fault-bars, defective barbule formations that may represent predilection sites for breakage in the feathers (O'Connor 1977). If fat stores are depleted, birds start to compensate by using protein, catabolising muscle tissue (Snyder and Terry 1986). This effect can cause the release of endogenous corticosterone, detrimental while feathers are developing (Macwhirter 1999; Flammer and Clubb 1999). Desrocher et al. (2009) observed how endogenous corticosterone in passerines released under physical stressors (food restriction) resulted in greater inter-barb distances in primaries, secondaries and rectrices, fewer barbules and weaker feathers when compared to control birds.

During the hand rearing process, begging behaviour was recorded for the birds in the different diet groups. Begging behaviour is essential in a healthy nestling to get the parents' attention (Lotem 1997; Leonard et al. 2000; Bize and Roulin 2006), and was observed in all birds in both insect diet groups; even in severe cases, where initially the chicks had to be force fed, they started begging for food within a short period of time. Conversely, in nestlings in the non-insect diet groups, begging behaviour was infrequent, particularly in the kibble diet group, thus requiring force feeding throughout the hand-rearing process. One important concern in the non-insect diet groups was how even the few nestlings that were begging refused repeatedly to swallow a house cricket.

Klasing (1998) described how birds adapted to soft foods are typically unwilling to consume significant quantities of hard foods if they suddenly become available, although this occurs in species adapted to such changes in diet (e.g. granivores). Piersma et al. (1993) summarised some studies that show how birds consuming soft foods have smaller gizzards than when they eat harder foods. Captive shorebirds, acclimatised to soft foods, initially did not consume their introduced natural hard-shelled food until a period that appeared to correspond with the enlargement and adaptation of the gizzard to the new hard food. Kasarov (1996) reviewed how digestive features are influenced by factors such as diet quality and quantity. Plasticity of the digestive tract includes changes in the size and musculature of the different organs, changes in pancreatic enzyme levels, and changes in absorption rates and retention times. Given these considerations, common swifts may be affected physiologically when changing from a soft rat mince or kibble with a yogurt-like texture to the new air-borne diet. For instance, they may need to strengthen the gizzard to assimilate the exoskeletons of the new natural diet. These are physical adaptations that may require several weeks for completion (Kasarov 1996; Klasing 1998) and this possibility is therefore of some concern.

Focusing now on some aspects of the individual diets, we noticed that the daily amount we were able to administer with the kibble formula was lower than for the other three diets (Table 1). The creator of the FoNS© formula (Winn, pers. comm.) suggested that low weight progression observed on the kibble diet could be attributable to a lower overall caloric intake rather than the composition of the diet per se. In addition, she observed that the cat food brand we used (Orijen®) was different from the original (Evo®), and might perform differently. Winn explained the success of the original formula when hand-rearing chimney swifts, describing how they were fed as much as they would eat every hour for 12 hours a day. However, although we increased feeding frequency to eight times per day versus five for the other three diets, weight gain was not achieved. Birds seemed unable to digest the food during those shorter intervals, as they presented hard gizzards and a distended digestive tract.

The use of mealworms has been somewhat controversial among the common swift rehabilitation community in Europe. Some claim that the chitin of mealworms may contain substances that cause liver and kidney intoxication in common swifts when fed for long periods, although we found no published data on such incidents. A negative point of mealworms, although this is shared with all commercially produced insects, is the unbalanced composition of vitamins and minerals. We proved that the mealworm diet did not cause histological lesions in major internal organs when administered for a period of 20 days in three animals. All animals had excellent body condition with fat stores that could possibly provide the energy necessary for the migration. All three animals had high cholesterol levels, even though no reference values were found for the species. It was assumed that the animals were starved for at least 8h prior to sampling but this could not be totally confirmed. Further work is needed to establish normal reference values for the species and thus permit the interpretation of biochemistry results from animals receiving different artificial diets.

Barker et al. (1998) described how chitin, measured as neutral detergent fibre, comprised about 15% of dry matter in many cultured insect species, with a higher content in house crickets (19.1%) when compared to mealworms (14.5%). Few studies related to chitin digestibility have been conducted on wild birds (Weiser et al. 1997; Akaki and Duke 1999) or on poultry (Hossain and Blair 2007), although none exposed any adverse health effects. When comparing mealworm and cricket nutrients, we observed that crude protein was similar in both insect species (about 19%). Larval stages, as in mealworms, have a higher fat content than adult insects (e.g. dry matter: mealworm 31.1% vs adult cricket 22.8%) (Baker et al. 1998). Fat has a higher calorific content than protein, providing a more concentrated energy source. Fat content also has an influence on the rate of food passage – as the fat content increases, the rate of passage is slowed. This effect improves digestibility of most nutrients, increasing exposure to digestive enzymes and time for absorption (Brue 1999). Fat provides the essential unsaturated fatty acids such as linoleic acid required for good growth (Snyder and Terry 1986), with mealworms an especially rich source of linoleic acid (Finke and Winn 2004).

In general terms, any hand-rearing formula needs a balance of calcium and phosphorus between 1.5:1 and 2:1 in order to avoid the development of metabolic bone disease and contribute to proper growth and health (Brue 1999; Duerr 2007). Baker et al. (1998) noted that most cultured insects, including mealworms and house crickets, were a poor source of calcium, with inverse calcium: phosphorus ratios. Copper, iron, magnesium and zinc, though not manganese, were adequate in terms of dietary requirements. As far as vitamins are concerned, most cultured insects but also free-ranging insects are low, particularly in vitamin A. Supplements of those nutrients most likely to be missing in commercially-supplied invertebrates, especially calcium and vitamin A, should therefore be used, though levels should be carefully controlled. Excessive calcium intake (when combined with vitamin D) in birds may cause kidney damage and secondary visceral or articular gout, while excess vitamin A can interfere with bone growth and disrupt epithelial cells, causing lesions in the mouth, nares and eyes (Klassing 1998; Brue 1999). Interestingly, Kyle and Kyle (2007) noted that metabolic bone disease in chimney swifts was rare, and thus low calcium concentrations in their diet might not be of particular concern.

Overall, we can recommend the use of mealworms, as long as a supplementation regime is strictly followed, when the cricket diet (Haupt 2009) cannot be provided for economic reasons. Possibly, a combination of both insects and even adding other species (cockroaches, wax worms or fruit flies) would enrich the diet. Kyle and Kyle (2007) have also stressed the importance of diet in the successful hand-rearing of chimney swifts, measured as high survival and release rates of raised birds, as well as extensive post-release breeding success, and post-migration data on many hand-reared individuals studied over a 20-year period.

Probably only a small percentage of even wild-raised nestlings survive to reproduce. We cannot provide for the needs of orphaned common swifts as their parents do, but we must emulate them as closely as possible if we want to give them any chance at all of survival, initially for the long migration journey, and then to reproductive age.

Conclusions

1. Final fledgling weights, feather condition and flight performance on both non-insect diets, rat mince and kibble diet, were questionable when compared to wild-raised birds, while the same variables were considered optimal in all clinical conditions for the insect diets. We anticipate that final weight could even be increased on both insect diets if feeding intake had been improved.

2. The results demonstrated the success of both insect diets when recovering nestlings in poor condition, even if severely emaciated, and highlighted the fact that all birds, regardless of condition, had a high possibility of survival, making a sacrifice protocol based on poor clinical condition at admission superfluous.
3. There are concerns about the use of mealworms in hand-rearing common swifts, even though they have proved successful when hand-rearing chimney swifts. This should be scientifically investigated.
4. Research on post-release survival should be encouraged. Knowing if hand-reared young have managed to forage and survive for a while would mean an initial success. Other research should also include morphological features, such as plumage quality compared to the wild.
5. The authors recommend that rehabilitators who have created their own diet analyse it thoroughly, observing carefully the final results when compared to wild conspecifics. Even birds that appear to be healthy may be undernourished on rehabilitation diets, leading to animals with weak bones, delayed growth and consequent lack of biological fitness.
6. The authors recommend discontinuing the use of the non-insect diets analysed in this study, and switching to an insect diet. Mealworms, which are considerable cheaper than house crickets, seem to be an excellent alternative as a base diet for hand-rearing common swifts when the established cricket diet cannot be provided for economic reasons.

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