ACCRETION OF NITROGEN AND MINERALS IN SUCKLING BATS.  
MYOTIS VELIFER AND TADARIDA BRASILIENSIS

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Levels of nitrogen, sodium, potassium, magnesium, calcium, and iron were determined for suckling young of known-age, lactating Myotis velifer and Tadarida brasiliensis, and milk from T. brasiliensis nursing known-age young. From birth to weaning, relationships of both nutrient concentrations and nutrient accretion to age are similar for both species but differ for each nutrient and generally reach adult concentration by weaning. While total mass of body sodium and potassium reach adult levels in both species well before weaning, levels of other elements do not. Although comparable data are limited, element concentrations in suckling bats are similar to those for other suckling small mammals and nesting birds. Growth requirements for measured nutrients in these bats are lower than published values for rodents. Most mineral nutrients that were measured in milk for T. brasiliensis varied with stage of lactation and were comparable in concentration with milk of other mammals. Using daily accretion of nutrients and their concentrations in milk, we calculated the minimal mass of milk needed to meet growth requirements in suckling T. brasiliensis. Among measured nutrients, calcium is the limiting nutritional factor that determines mass of milk needed by suckling young during postnatal growth.

Key words: bat, Chiroptera, nitrogen accretion, mineral accretion, nutrition, milk composition, postnatal growth, Myotis velifer, Tadarida brasiliensis

Studies of postnatal growth and development in bats, as well as in other small mammals, have focused on morphologic changes (primarily skeletal characteristics) or changes in body mass (Kunz, 1987; Kunz and Allgaier, in press; Tuttle and Stevenson, 1982). Accretion of body mass during growth in suckling bats has been incorporated into energy budgets for lactating females; however, no data are available on composition and accretion of nitrogen or minerals. Data on nutrient budgets of nesting birds are similarly limited (O'Connor, 1983; Pinowski et al., 1983; Ricklefs, 1984; Taylor and Konarzewski, 1992). Most studies on body composition of nitrogen and minerals in birds (Sturges et al., 1974) and small mammals (Gentry et al., 1975) have focused on adults. Data on elemental composition in small mammals during postnatal growth appear to be limited to Peromyscus polionotus, Sigmodon hispidus, and Mus musculus (Gentry et al., 1975). The paucity of data on nitrogen and mineral requirements of suckling small mammals underscores how little is known about nutrient metabolism during the postnatal period. While data on macromolecular constituents, composition, and energy content of milk of bats are available (reviewed by Jenness and Studier, 1976; Kunz et al., 1983, in press b), information on mineral composition of milk in these animals is essentially lacking.

This study was designed to assess changes in selected nutrient budgets during the suckling period in two species of insectivorous bats (Myotis velifer and Tadarida brasiliensis). We collected data on newborn and suckling young of known age, lactating T. brasiliensis and M. velifer, and milk from T. brasiliensis that were nursing known-age young. Changes in live mass, water content, dry mass, and fat content during postnatal growth will be described.
elsewhere. In this paper, we describe postnatal changes in levels of nitrogen and selected minerals (sodium, potassium, magnesium, calcium, and total iron) during the suckling period. These data are used to estimate daily accretion of each nutrient and minimum amounts of milk required by suckling young to meet daily nutrient requirements.

**Materials and Methods**

Young *M. velifer* and *T. brasiensis* were collected from Ekhart James River Cave, Mason Co., near Mason, Texas, from mid-May through June of 1987 and 1988. Most young were captured in the maternity roost between 2100 and 2200 h, soon after their mothers emerged to feed. After young bats became volant, individuals were captured at their roost during midday (1300–1500 h). Young ranged in age from newborns to those that had begun to fly. We determined sex, mass to the nearest 0.05 g using an Ohaus portable electronic balance, and length of forearm and fourth metacarpal-phalangeal epiphysial gap of each young bat (Kunz and Anthony, 1982). We used equations derived from these measurements to estimate age of each young bat. Lactating *M. velifer* and *T. brasiensis* were collected 13–25 June 1988. After being euthanized by cardiac compression, each bat was sealed in a labeled plastic bag, stored in a portable cooler (for ca. 2 h) containing a frozen gel-pak, and subsequently kept in a freezer at −20°C. All specimens were shipped on dry ice to Boston, Massachusetts, and were stored in a standard freezer until they were analyzed.

To collect milk from *T. brasiensis*, mother-young pairs were captured after mothers returned from their second feeding bout (near dawn) in late June through early July 1991. Each mother-young pair was placed in a separate holding bag and removed from the cave for processing. Mothers and young were separated, marked with plastic split-ring bands (A. C. Hughes), and housed in simulated roosts to minimize stress (Kunz and Kurta, 1988). We assigned day of lactation from age of attached young derived from predictive equations established for each species.

Within 30 min of capture, mothers were injected intraperitoneally with 2 μl/g of synthetic oxytocin (200 I.U./ml) to promote milk letdown. Milk was expressed from the mammary glands by hand palpation 5 min later. Milk was transferred to 1-ml Eppendorf tubes using a Gelman SAFE mouth pipette and nonheparinized microcapillary tube. Milk samples were refrigerated at −20°C soon after collection and later stored at −80°C until they were analyzed for nitrogen and minerals.

After thawing at room temperature, each animal was reweighed to the nearest 0.1 mg following removal of contents of stomach and intestines, which were examined for the presence of milk and remains of insects. Carcasses subsequently were minced and dried to constant mass at 60°C in a convection oven. Lipids were extracted from the dried, minced carcasses using a 3:1 (v/v) ethanol:petroleum ether solvent in a Soxhlet extraction apparatus. After lipid extraction, lean dry mass was determined by redrying carcasses to constant mass. Each lean, dry carcass was pulverized in a Wiley Mill using a 40-mm mesh sieve, transferred to a glass vial, stored in a desiccator, and shipped to Flint, Michigan, for nitrogen and mineral analyses.

To avoid potential sampling errors, we analyzed duplicate, triplicate, or quadruplicate subsamples of each ground carcass. Average values for each element were derived for each individual. We weighed ground samples (ca. 200–350 mg) of each carcass to the nearest 0.1 mg and digested those samples in 250-ml volumetric flasks with 2.5 ml of boiling, reagent-grade H₂SO₄, followed by the addition of 7.5 ml of per-sulfuric acid (30% H₂O₂: H₂SO₄, 2:1, v/v). We extruded frozen samples of milk onto cleaned, preweighed glass coverslips to determine wet mass (to 0.1 mg) of each milk sample. Those samples were dried to constant weight at 50–60°C and reweighed to determine dry mass. Coverslips with samples of dry milk subsequently were broken into 100-ml volumetric flasks for digestion. We analyzed digested samples, after appropriate dilution, for nitrogen, sodium, potassium, magnesium, calcium, and total iron. Procedural details are given in Studier and Sevick (1992). Data were analyzed using SYSTAT (Wilkinson, 1989). Figures were created with DeltaGraph.

**Results**

Concentrations of measured elements are less variable when expressed on a basis of dry mass or lean, dry mass. In addition to
total body level, we have chosen to report body composition on the basis of live mass, which is more routinely measured and more comparable to limited published data (Appendix I). Compositions and accretion based on dry mass or lean, dry mass can be calculated from equations we developed.

Few differences are found in elemental concentrations in lactating females of the two species (Appendix I). Iron concentrations are marginally higher in *T. brasilienensis* than in *M. velifer* (*t* = 2.47, *d.f.* = 11, *P* < 0.05) and potassium concentrations are significantly higher in *M. velifer* than in *T. brasilienensis* (*t* = 6.44, *d.f.* = 11, *P* < 0.001). Absolute amounts of each measured element tend to be higher in the larger *T. brasilienensis* than in *M. velifer* (iron, calcium, and nitrogen; *t*-tests, *P* < 0.01 in each case); however, absolute levels of potassium are higher in *M. velifer* than in *T. brasilienensis* (*t* = 3.42, *d.f.* = 11, *P* < 0.01).

Except for levels of potassium and sodium in *T. brasilienensis*, elemental concentrations in milligrams per gram of live mass relate significantly to age in young of both species tested (Appendix II). Although quite variable, the most typical relationship of elemental concentration to age of young is exemplified by levels of calcium in *T. brasilienensis* (Fig. 1). In that case, concentration decreases to a minimum during the early suckling period and rises rapidly during the late suckling period (concave upward). Such elements, therefore, accumulate in the body less rapidly than live mass increases during the early suckling period, and accrete more rapidly than live mass increases late in the suckling period. Concentrations of sodium (Fig. 1) and potassium in young *T. brasilienensis* remain constant throughout the nursing period and are the only measured nutrients that accumulate at the same rate as live mass. Levels of sodium in suckling *M. velifer* increase early during postnatal growth and decrease during later postnatal growth (concave downward), when rates of sodium accretion are less rapid than growth as live mass.

![Graph](image)

**Fig. 1.**—Concentrations (mg/g live mass = LM) of calcium, sodium, and iron in known-age, suckling young of *M. velifer* (closed squares, birth through 37 days old) and *T. brasilienensis* (closed circles, birth through 40 days old). Lines shown are solutions to polynomial-regression equations (see Appendix II for additional information).

postnatal growth, concentrations of iron in young of both species increase significantly in positive fashion (Fig. 1); thus, iron accumulates more rapidly than live mass throughout all of postnatal growth.

Based on coefficients of determination (*r*²), relationships of total body content (mg) to age (Appendix III) are much more predictive than are age-related concentrations of nutrients (Appendix II). In both species, total calcium content continuously increases with age in a curvilinear fashion
where the curve is concave upward (Fig. 2A), which translates into progressive accretion for that element (Fig. 2A, insert). Accretion rate is determined by solving the equations for total nutrient mass to age (Appendix III) for each day of suckling and then subtracting total body mass for any day from its successive day. As an example, for postnatal interval of day 10–11 for *M. velifer*, total body calcium increases from 28.26 to 30.15 mg for an accretion of 1.9 mg on postnatal day 10. The pattern of accretion for calcium is unique among measured nutrients. Typically, total body content of a nutrient increases in a linear or curvilinear, concave downward fashion (Appendix III) to reach, e.g., potassium and sodium (Fig. 2B), or approach peak levels of elements, e.g., for magnesium, nitrogen, and iron (Fig. 2C). Daily accretion for those elements that relate linearly to age are then constant, such as iron in *T. brasiliensis* (Fig. 2C, insert). In elements that are curvilinearly (concave downward) related to age of young, daily accretion progressively decreases. That pattern occurs for sodium in both species (Fig. 2B, insert) and iron in *M. velifer* (Fig. 2C, insert).

Elemental concentrations in milk from *T. brasiliensis* nursing known-age young are summarized in Table 1. Regression analyses by element of those samples with dry masses of >9.9 mg found significant linear relationships (coefficients ± 1 SE) between levels of calcium (*F* = 4.93; *d.f.* = 1.31; *P* = 0.033; *r*² = 0.137), magnesium (*F* = 9.12; *d.f.* = 1.31; *P* = 0.005; *r*² = 0.227), and sodium (*F* = 8.39; *d.f.* = 1.31; *P* = 0.006; *r*² = 0.213) and suckling day (age) as follows: calcium (mg/g wet mass) = −0.0293 (± 0.0132) age + 2.29 (± 0.17); magnesium (mg/g wet mass) = −4.57 × 10⁻¹ (± 1.5 × 10⁻¹) age + 0.214 (± 0.019); sodium (mg/g wet mass) = −0.0285 (± 0.0098) age + 0.755 (± 0.127).

**DISCUSSION**

Data on elemental composition of the body and accretion of nutrients during post-natal interval suggest that each element that relates linearly to age may be stored as a constant daily amount following a linear function (Appendix III). In contrast, the concave downward relationship of magnesium, nitrogen, and iron may reflect their storage as a constant daily amount following a curvilinear function (Appendix III). Therefore, the daily accretion of nutrients follows a curvilinear function (Appendix III) related to age of young (Fig. 2C, insert), and the daily accretion of nutrients follows a linear function (Appendix III) related to age of young (Fig. 2C, insert).

**Fig. 2.**—Total body calcium (A), sodium (B), and iron (C) in newborn (open circles at day 0), known-age young (closed circles), and lactating (open circles plotted at day 48) *T. brasiliensis* and known-age young (closed squares) and lactating (open squares plotted at day 46) *M. velifer*. Lines shown represent solutions to polynomial-regression equations (Appendix III). Insert shows daily calcium (A), sodium (B), and iron (C) accretion (mg/day) in young of both species.
Table 1. Elemental composition (in mg/g wet mass and mg/g dry mass) in milk of mothers nursing known-age young (1–25 days old) T. brasiliensis. Average water content of milk samples (±1 SE) was 68.37 ± 0.48% of wet mass. Values shown are means ± 1 SE. Concentrations of calcium, magnesium, and sodium vary with nursing day.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Fe</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>Na</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mg/g wet mass</td>
<td>40</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>(±0.002)</td>
<td>(±0.059)</td>
<td>(±0.006)</td>
<td>(±0.055)</td>
<td>(±0.049)</td>
<td>(±1.46)</td>
</tr>
<tr>
<td>mg/g dry mass</td>
<td>0.127</td>
<td>6.109</td>
<td>0.505</td>
<td>3.456</td>
<td>1.499</td>
<td>54.25</td>
</tr>
<tr>
<td></td>
<td>(±0.007)</td>
<td>(±0.188)</td>
<td>(±0.021)</td>
<td>(±0.173)</td>
<td>(±0.156)</td>
<td>(±4.60)</td>
</tr>
</tbody>
</table>

Postnatal growth in bats and other mammals are severely limited. Results for bats cannot be compared easily with other mammals because species that routinely give birth to single young often are large, aquatic, or both, and are never insectivorous. Terrestrial mammals comparable in size with bats often are not insectivorous and give birth to many young in a litter. Such young often forage while feeding on mother’s milk and are weaned long before they reach adult size. Avian clutches also are frequently greater than one, and data on small (<15 g) avian species are not available. Comparison of our data to body composition and accretion in small, altricial, insectivorous, nestling birds, however, may be as appropriate as comparisons with other mammals. Comparison with domesticated or laboratory-reared birds or mammals that have been artificially selected for rapid growth on idealized foods is inappropriate. Given these caveats and cautions, body concentrations of nitrogen and minerals are remarkably consistent in growing young in the few species previously studied (Table 2). The remarkable consistency of body composition in nestling birds and suckling mammals suggests that differences in absolute rates of accretion are largely explained by similar differences in size and, therefore, in growth rates.

Values given in Table 2 represent average body composition for measured elements in growing young. For many of these elements, body concentrations change considerably over time (Appendix II). For all species reported in Table 2, concentrations of body calcium (mg/g live mass) increase markedly over time from birth through weaning or fledging, whereas sodium and potassium levels remain constant or decrease. During postnatal growth, levels of nitrogen, magnesium, and iron increase, decrease, or remain constant in various species. Although our data on adult body composition are limited, concentrations of nitrogen and minerals (Appendix I) compare favorably with data for birds (Sturges et al., 1974) and other small mammals (Gentry et al., 1975).

Considering the great range in body sizes, caloric density of milk and numbers of offspring suckled, concentrations of nitrogen and minerals in mammalian milks are remarkably consistent (Table 3). Composition of milk compares nicely with similar concentrations of body elements found during postnatal growth. Concentrations of nitrogen and minerals in mammalian milks change during lactation in varying patterns. In T. brasiliensis, concentrations of calcium, magnesium, and sodium in milk decrease over time; whereas levels of potassium, nitrogen (protein), and iron remain constant. Data on macromolecular composition of milk of T. brasiliensis and M. velifer show that fat levels increase, but protein and carbohydrate concentrations remain constant throughout lactation (Kunz et al., in press b). In laboratory mice, levels of calcium and magnesium in milk remain
TABLE 2.—Body concentrations (mg/g dry mass) of nitrogen and selected minerals in some nesting birds and suckling small mammals. Values shown are averages taken directly or estimated from data given in references.

<table>
<thead>
<tr>
<th>Species</th>
<th>Fledgling or suckling weaning body mass (g)</th>
<th>Ca</th>
<th>Na</th>
<th>K</th>
<th>Mg</th>
<th>Fe</th>
<th>N</th>
<th>Reference</th>
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<tbody>
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<td>Anthus pratensis</td>
<td>17.0</td>
<td>0.9</td>
<td>19.0</td>
<td>6.0</td>
<td>10.0</td>
<td>1.3</td>
<td>0.35</td>
<td>105.0</td>
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<tr>
<td>Stadilus sialis</td>
<td>28.0</td>
<td>1.6</td>
<td>14.8</td>
<td>10.8</td>
<td>15.7</td>
<td>1.3</td>
<td>0.21</td>
<td>148.0</td>
</tr>
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<td>Turdus philomelos</td>
<td>50.0</td>
<td>3.6</td>
<td>13.6</td>
<td>14.6</td>
<td>13.6</td>
<td>1.3</td>
<td></td>
<td>126.0</td>
</tr>
<tr>
<td>Turdus merula</td>
<td>70.0</td>
<td>5.2</td>
<td>16.5</td>
<td>17.0</td>
<td>11.3</td>
<td>1.3</td>
<td></td>
<td>106.0</td>
</tr>
<tr>
<td>Alle alle</td>
<td>110.0</td>
<td>3.7</td>
<td>14.0</td>
<td>7.0</td>
<td>0.8</td>
<td></td>
<td>90.0</td>
<td>1971</td>
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<tr>
<td>Corvus frugilegus</td>
<td>390.0</td>
<td>12.0</td>
<td>18.0</td>
<td>5.0</td>
<td>9.0</td>
<td>0.8</td>
<td>0.40</td>
<td>85.0</td>
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<tr>
<td>Peromyscus polionotus</td>
<td>67.7</td>
<td>0.24</td>
<td>14.0</td>
<td>4.0</td>
<td>10.3</td>
<td>0.5</td>
<td>0.29</td>
<td>Gentry et al., 1975</td>
</tr>
<tr>
<td>Sigmodon hispidus</td>
<td>17.1</td>
<td>0.88</td>
<td>34.0</td>
<td>4.5</td>
<td>13.6</td>
<td>1.5</td>
<td>0.16</td>
<td>93.0</td>
</tr>
<tr>
<td>Tadarida brasiliensis</td>
<td>11.1</td>
<td>0.21</td>
<td>21.8</td>
<td>3.0</td>
<td>6.8</td>
<td>1.7</td>
<td>0.34</td>
<td>138.0 Present study</td>
</tr>
<tr>
<td>Myotis velifer</td>
<td>8.6</td>
<td>0.20</td>
<td>23.0</td>
<td>4.0</td>
<td>9.3</td>
<td>1.5</td>
<td>0.41</td>
<td>Present study</td>
</tr>
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</table>

constant, whereas levels of iron decrease linearly and levels of nitrogen decrease curvilinearly over time (Reis et al., 1991). In guinea pigs levels of calcium, magnesium, sodium, and iron in milk rise curvilinearly and levels of potassium decrease curvilinearly over time (Anderson, 1990; Anderson and Sheffield, 1988). In milk of laboratory rats, levels of calcium, magnesium, and nitrogen increase and then decrease (each element: Keen et al., 1981), increase and remain constant (calcium), or remain constant (magnesium and nitrogen) throughout lactation (Nicholas and Hartmann, 1991). Additionally, concentrations of sodium, potassium, and iron in milk of laboratory rats

TABLE 3.—Mineral composition (averages in mg/g wet mass) of milks of Tadarida brasiliensis and other mammals.

<table>
<thead>
<tr>
<th>Species</th>
<th>Na⁺</th>
<th>K⁺</th>
<th>Ca²⁺</th>
<th>Mg²⁺</th>
<th>Fe</th>
<th>Source</th>
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<tr>
<td>Tadarida brasiliensis</td>
<td>0.47</td>
<td>1.09</td>
<td>1.93</td>
<td>0.160</td>
<td>0.040</td>
<td>Present study</td>
</tr>
<tr>
<td>Homo sapiens</td>
<td>0.13</td>
<td>0.45</td>
<td>0.35</td>
<td>0.050</td>
<td>0.007</td>
<td>Diem, 1962</td>
</tr>
<tr>
<td>Capra hircus</td>
<td>0.34</td>
<td>1.80</td>
<td>1.28</td>
<td>0.133</td>
<td>0.002</td>
<td>Diem, 1962</td>
</tr>
<tr>
<td>Ovis aries</td>
<td>0.33</td>
<td>1.88</td>
<td>2.07</td>
<td>0.083</td>
<td>0.002</td>
<td>Diem, 1962</td>
</tr>
<tr>
<td>Bos taurus</td>
<td>0.58</td>
<td>1.38</td>
<td>1.25</td>
<td>0.130</td>
<td>0.002</td>
<td>Diem, 1962</td>
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<td>Rangifer tarandus</td>
<td>1.57</td>
<td>1.59</td>
<td>2.54</td>
<td>0.001</td>
<td>0.001</td>
<td>Watt and Merrill, 1963</td>
</tr>
<tr>
<td>Equus zebra</td>
<td>0.24</td>
<td>0.51</td>
<td>0.97</td>
<td>0.100</td>
<td>0.002</td>
<td>Schryver et al., 1986</td>
</tr>
<tr>
<td>Equus przewalski</td>
<td>0.18</td>
<td>0.47</td>
<td>1.09</td>
<td>0.083</td>
<td>0.001</td>
<td>Schryver et al., 1986</td>
</tr>
<tr>
<td>Equus burchelli</td>
<td>0.28</td>
<td>0.19</td>
<td>0.69</td>
<td>0.093</td>
<td>0.002</td>
<td>Schryver et al., 1986</td>
</tr>
<tr>
<td>Equus caballus</td>
<td>0.16</td>
<td>0.45</td>
<td>1.01</td>
<td>0.076</td>
<td>&lt;0.001</td>
<td>Schryver et al., 1986</td>
</tr>
<tr>
<td>Rattus norvegicus</td>
<td>0.69</td>
<td>1.37</td>
<td>2.40</td>
<td>0.219</td>
<td>0.053</td>
<td>Nicholas and Hartman, 1991</td>
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<td>Phoca groenlandica</td>
<td>0.70</td>
<td>0.46</td>
<td>0.95</td>
<td>0.104</td>
<td>0.053</td>
<td>Webb et al., 1984</td>
</tr>
<tr>
<td>Mesoplodon stejnegeri</td>
<td>1.30</td>
<td>1.10</td>
<td>2.20</td>
<td>0.042</td>
<td>0.035</td>
<td>Ullrey et al., 1984</td>
</tr>
<tr>
<td>Lepus europaenus</td>
<td>0.95</td>
<td>1.90</td>
<td>5.45</td>
<td>0.520</td>
<td>0.004</td>
<td>Lhullery et al., 1984</td>
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decrease curvilinearly over time (Keen et al., 1981; Nicholas and Hartmann, 1991).

Our measurements of rates of accretion of nitrogen and minerals in young of *T. brasiliensis*, coupled with measurements of levels of those nutrients in their mother’s milk over time, allow us to calculate a minimal mass of milk (at 100% assimilation efficiency by sucklings) needed daily to meet measured accretion for each element. For all measured nutrients except calcium, minimum mass of milk required to meet daily accretion remains constant or decreases over time (Fig. 3). Of the nutrients reported here, therefore, accretion of calcium in suckling young represents the limiting factor that determines the daily, minimal amount of milk that must be ingested by young of *T. brasiliensis*. Requirements for milk production based on calcium accretion (Fig. 3) are similar to estimates based on energetic considerations in *T. brasiliensis* during their postnatal growth (Kunz et al., in press a, in press b).

Kunz et al. (in press a) estimate that ingestion by *T. brasiliensis* of dry insect mass of 1.86 and 3.39 g/day in early and midlactation, respectively, will meet the energy requirements of lactating females. Those data, coupled with rates of nutrient accretion presented here (Appendix II), allow us to calculate the minimal concentration of each measured nutrient that must be present in insects eaten. These minimal concentrations have been adjusted by assuming an 88% assimilation efficiency by lactating *T. brasiliensis* (Anthony and Kunz, 1977) and 100% assimilation efficiency from the milk ingested by suckling young (Table 4). Calculations shown in Table 4 also assume a gross efficiency of milk production of 100% for each incorporated nutrient. Such an assumed efficiency is certainly not valid for energy accretion that reaches a maximal reported value of 40% (Dryden and Anderson, 1978; Kunz, 1987). Using data from Table 4, the previously stated assumptions, and nutrient composition of insects (Studier and Sevick, 1992) eaten by lactating *T. brasiliensis* (Kunz et al., in press a), we calculated that the amount of dry mass of insects needed to meet caloric needs greatly exceeds requirements for all measured nutrients except calcium and, perhaps, sodium. The minimal level of sodium in insects consumed by lactating *T. brasiliensis* (hymenopterans, coleopterans, lepidopterans, dipterans, and homopterans—Kunz et al., in press a) is 0.544 mg/g dry mass, which is well above the 0.0875 mg/g dry mass minimally required in early lactation. Because many lepidopterans available to bats as potential prey contain no measurable sodium (Studier et al., 1994), consumption of such moths alone would place lactating females into a sodium deficit.

<table>
<thead>
<tr>
<th>Element</th>
<th>Early Lactation</th>
<th>Midlactation</th>
</tr>
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<tbody>
<tr>
<td>Ca</td>
<td>1.01</td>
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</tr>
<tr>
<td>Fe</td>
<td>0.0128</td>
<td>0.0070</td>
</tr>
<tr>
<td>Mg</td>
<td>0.0599</td>
<td>0.0198</td>
</tr>
<tr>
<td>Na</td>
<td>0.0875</td>
<td>0.0229</td>
</tr>
<tr>
<td>K</td>
<td>0.258</td>
<td>0.0433</td>
</tr>
<tr>
<td>N</td>
<td>4.88</td>
<td>1.99</td>
</tr>
</tbody>
</table>
Because minimal requirements given in Table 4 easily can be low by a factor of two, insect prey with calcium levels <2 mg/g dry mass that are consumed by lactating T. brasiliensis would probably be insufficient to meet calcium needs. Because calcium levels average 0.759, 1.050, 1.221, 1.471, and 2.271 mg/g dry mass for hymenopterans, coleopterans, lepidopterans, dipterans, and homopterans, respectively (Studier and Sevick, 1992), lactating T. brasiliensis almost certainly are in negative calcium balance throughout most of lactation. Such negative or marginal calcium budgets previously have been reported for insectivorous, nesting birds (Hungerford et al., 1993; Turner, 1982) and lactating big brown bats (Studier et al., 1991, 1994).

ACKNOWLEDGMENTS

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LITERATURE CITED


Associate Editor was Patricia W. Freeman.
APPENDIX I

Elemental concentrations (mg/g live mass) and total level (mg) in newborn, young, and lactating female (adult) Myotis velifer and Tadarida brasiliensis (sample sizes in parentheses). Values given are X ± 1 SE.

<table>
<thead>
<tr>
<th>Concentration or level</th>
<th>Myotis velifer</th>
<th>Tadarida brasiliensis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young (29)</td>
<td>Adult (7)</td>
</tr>
<tr>
<td>Fe</td>
<td>0.115 ± 0.004</td>
<td>0.139 ± 0.002</td>
</tr>
<tr>
<td>Mg</td>
<td>0.420 ± 0.018</td>
<td>0.597 ± 0.012</td>
</tr>
<tr>
<td>Ca</td>
<td>9.910 ± 0.555</td>
<td>16.534 ± 0.314</td>
</tr>
<tr>
<td>Na</td>
<td>1.081 ± 0.035</td>
<td>0.810 ± 0.025</td>
</tr>
<tr>
<td>K</td>
<td>2.531 ± 0.092</td>
<td>2.063 ± 0.026</td>
</tr>
<tr>
<td>N</td>
<td>38.60 ± 1.09</td>
<td>41.42 ± 0.63</td>
</tr>
</tbody>
</table>

Total level

| Fe                    | 0.4700 ± 0.0343 | 0.9900 ± 0.0076 | 0.1521 ± 0.0106 | 0.4465 ± 0.0483 | 1.2170 ± 0.0599 |
| Mg                    | 1.679 ± 0.164   | 4.089 ± 0.117    | 0.964 ± 0.057   | 2.120 ± 0.151   | 4.316 ± 0.154   |
| Ca                    | 41.46 ± 4.60    | 117.7 ± 3.1      | 25.71 ± 1.36    | 52.39 ± 4.44    | 139.6 ± 6.3     |
| Na                    | 4.236 ± 0.309   | 5.767 ± 0.222    | 1.903 ± 0.078   | 3.531 ± 0.202   | 5.750 ± 0.402   |
| K                     | 10.09 ± 0.79    | 14.67 ± 0.26     | 3.696 ± 0.147   | 7.960 ± 0.482   | 12.53 ± 0.57    |
| N                     | 155.1 ± 13.0    | 294.3 ± 4.1      | 78.79 ± 3.17    | 170.9 ± 14.1    | 344.2 ± 11.7    |

APPENDIX II

Regression equations for total body concentration of tested elements (in mg/g live mass) as functions of age (days) in young Myotis velifer (n = 29) and Tadarida brasiliensis (n = 28). Values shown are coefficients ± 1 SE for curvilinear equations of the form y = ax^2 + bx + c or linear equations of the form y = bx + c. In all significant cases, P < 0.01.

<table>
<thead>
<tr>
<th>Element</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>F-value</th>
<th>d.f.</th>
<th>r^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myotis velifer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>0.00180</td>
<td>± 0.00020</td>
<td>0.0868</td>
<td>± 0.0038</td>
<td>84.3</td>
<td>1.27</td>
</tr>
<tr>
<td>Ca</td>
<td>0.00512</td>
<td>± 0.00148</td>
<td>0.0517</td>
<td>± 0.0565</td>
<td>7.16</td>
<td>0.40</td>
</tr>
<tr>
<td>Mg</td>
<td>0.00790</td>
<td>± 0.00034</td>
<td>0.296</td>
<td>± 0.008</td>
<td>162.1</td>
<td>2.26</td>
</tr>
<tr>
<td>Na</td>
<td>-0.00109</td>
<td>± 0.00027</td>
<td>0.0411</td>
<td>± 0.0104</td>
<td>0.852</td>
<td>0.073</td>
</tr>
<tr>
<td>K</td>
<td>-0.00217</td>
<td>± 0.00074</td>
<td>0.0937</td>
<td>± 0.0282</td>
<td>1.88</td>
<td>0.20</td>
</tr>
<tr>
<td>N</td>
<td>0.429</td>
<td>± 0.050</td>
<td>31.9</td>
<td>± 1.0</td>
<td>74.5</td>
<td>1.27</td>
</tr>
</tbody>
</table>

| Tadarida brasiliensis* |          |          |          |         |      |       |
| Fe              | 0.00268  | ± 0.00029 | 0.0656  | ± 0.0056 | 84.7 | 1.26  | 0.765 |
| Ca              | 0.0108   | ± 0.0023  | -0.239  | ± 0.089  | 12.7  | 0.7   | 0.25  |
| Mg              | 0.00406  | ± 0.00112 | 0.471   | ± 0.022 | 13.1  | 1.26  | 0.334 |
| N               | 0.553    | ± 0.087  | 33.9    | ± 1.7   | 40.2  | 1.26  | 0.607 |

* Not significant at 5% level for Na and K.
APPENDIX III

Regression equations for total body content of tested elements (in mg) as functions of age (days) in young Myotis velifer (n = 29) and Tadarida brasiliensis (n = 28). Values shown are coefficients ± 1 SE for curvilinear equations of the form \( y = ax^2 + bx + c \) or linear equations of the form \( y = bx + c \). In all cases, \( P < 0.0001 \).

<table>
<thead>
<tr>
<th>Element</th>
<th>Myotis velifer</th>
<th>Tadarida brasiliensis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( a )</td>
<td>( b )</td>
</tr>
<tr>
<td>Fe</td>
<td>(-2.87 \times 10^{-4} \pm 0.91 \times 10^{-4} )</td>
<td>0.0304 ± 0.0035</td>
</tr>
<tr>
<td>Ca</td>
<td>0.0156 ± 0.0058</td>
<td>1.56 ± 0.22</td>
</tr>
<tr>
<td>Mg</td>
<td>0.0746 ± 0.0033</td>
<td>0.508 ± 0.064</td>
</tr>
<tr>
<td>K</td>
<td>(-7.40 \times 10^{-3} \pm 0.15 \times 10^{-3} )</td>
<td>0.382 ± 0.055</td>
</tr>
<tr>
<td>N</td>
<td>0.0108 ± 0.0020</td>
<td>0.762 ± 0.142</td>
</tr>
<tr>
<td>Mg</td>
<td>(-1.12 \times 10^{-3} \pm 0.23 \times 10^{-3} )</td>
<td>0.108 ± 0.009</td>
</tr>
<tr>
<td>Ca</td>
<td>0.0114 ± 0.0039</td>
<td>1.55 ± 0.15</td>
</tr>
<tr>
<td>Na</td>
<td>(-2.20 \times 10^{-3} \pm 0.71 \times 10^{-3} )</td>
<td>0.163 ± 0.028</td>
</tr>
<tr>
<td>K</td>
<td>(-8.61 \times 10^{-3} \pm 1.75 \times 10^{-3} )</td>
<td>0.499 ± 0.069</td>
</tr>
<tr>
<td>N</td>
<td>(-0.0607 \pm 0.0193 )</td>
<td>8.54 ± 0.77</td>
</tr>
</tbody>
</table>