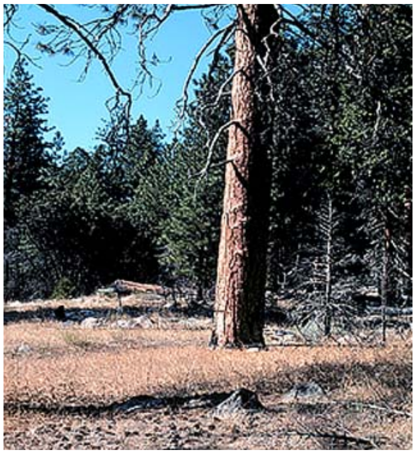


CONTRIBUTIONS

Commentary

A History of the Ecological Sciences, Part 9. Albertus Magnus: a Scholastic Naturalist

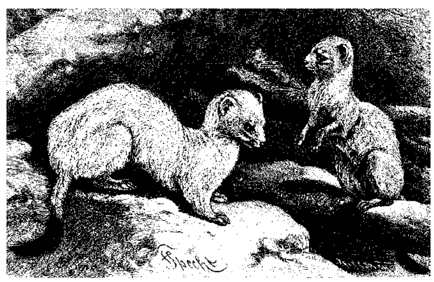
Medieval western Europe made a much greater investment in higher education than any other civilization ever had, and science was a prominent part of the curriculum. There is no simple explanation as to why this happened, but a strong demand developed for scholars educated in theology, law, or medicine, and, of course this created a demand for professors to educate them. Italian universities, which were the earliest, tended to be sponsored by cities, although Frederick II founded the University of Naples in 1224 as a state university to educate state officials who were not clergy. Elsewhere, universities were usually church sponsored, but even so, all universities in western Europe had much more autonomy than comparable institutions in other civilizations (Kibre and Siraisi 1978, Huff 1993: 149–201). A powerful stimulus to curriculum development was the translation of works by Aristotle and his Arabic commentators into Latin. Through much of the 1200s, there was a lively discussion between scholars and clergy over how appropriate it was to devote many courses to pagan learning. The Aristotelians, led by Albertus Magnus and his pupil Thomas Aquinas, pretty much won, although universities did agree not to debate heretical questions, such as the possible eternity of the universe (Grant 1974:42–52).

Albert the Great was from a noble family and was born about 1200 at the family castle of Lauingen. He grew up in the family manor in nearby Bollstädt, and was called Albert of Lauingen or Albert of Bollstädt. He studied liberal arts at the University of Padua, in Italy, and against the wishes of his family joined the Dominican Order. He was ordained in Germany and taught at several priories until he went to the University of Paris in 1240 or 1241. He earned an M.A. degree in theology and lectured there until 1248, when he went to Cologne to teach. Much of his time from 1253 to 1262 was devoted to administrative duties for the Catholic Church, after which he returned to teaching, preaching, and writing until his death in 1280 (Wallace 1970). The Dominicans have a strong commitment to teaching, and his brothers in the Order asked him to explain, in Latin, Aristotle's works. This task became his main life's work, and he was probably the most prolific author of the Middle Ages (Kitchell and Resnick 1999:18). He paraphrased all of Aristotle and added commentaries based upon his own observations and those of others.

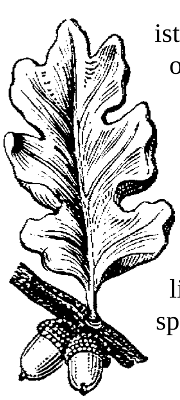
One of Albert's earliest works is *Liber de natura locorum*, on geography. He reviewed the ancient arguments against the possibility of people being able to live at the Equator, but dismissed them because both Ptolemy and Ibn Sina had seen men who lived between the Tropic of Cancer and the Equator, and it was known that people live at the Equator in Africa and in the [East] Indies (Tilmann 1971: 54). However, he knew that life at 56 degrees latitude was difficult, and therefore he did believe that the poles were uninhabitable; they may have day for half a year and night for half a year (Tilmann 1971:65). Animals, such as bears and lions, that live in polar regions tend to be white. The sea freezes in winter and icebergs float in the sea in summer (Tilmann 1971:67). Albert knew that the proximity of the sea modifies the climate of land, that high mountains can have perpetual snow, that mountains can also influence climate by blocking the wind, and that depressions of great depth can have noxious gas, as do swamps and some lakes (Tilmann 1971:86–89). He also thought that "lands situated in the middle of great forests or near the forest, always have a suffocating and a thick air, and they have much fog and many whirlwinds." It was not just forest in aggregate that was the problem, but also certain noxious trees: "walnut, the oak, and other trees which either by their bitterness, poison the air, or by their height confine the air, and do not permit it to escape and be purified." (Tilmann 1971:89–90).

He also thought that living beings are influenced by their localities: mountains, seas, woods, swamps, and so on.

"Men born in rocky places, level areas, and cold dry places are very strong and well-boned with visible joints. They are of noble stature, have skill and endurance in war, and have muscular limbs, and they have wild customs…." On the other hand, those who live "exposed to the south and not to other directions live poorly on account of the turbulent, warm, moist, and pestilential wind. Because their pores are opened on account of the heat, they must wear such clothing that will prevent the wind from penetrating to the marrow of their bones. Houses for them should be built with a strong protection from the south" (Tilmann 1971:106–107). The same was true for plants, animals, and stones. "This is the proof. Bears in cold and moist places, and rabbits in places rather moist, cold, and dry [sic], are white, while in other climates they tend toward blackness, darkness, or they are golden yellow" (Tilmann 1971:108).



He wrote *De vegetabilibus libri VII* during the 1250s, based upon *De plantis* by Nicolaus of Damascus (first century BC), which he assumed was by Aristotle. He saw that it was not as well written or organized as Aristotle's other works, but attributed this to a lack of understanding or skill by the translator (Alfred of Sarashel) from Arabic into Latin. *De vegetabilibus* has this organization: books I and IV paraphrase *De plantis*; books II and V are Albert's commentaries on *De plantis*; book III summarizes a discussion by Ibn Sina on seeds, fruits, and fruit juices; book VI is a herbal describing some 400 species, including habitats and locations; and book VII is on agriculture, based largely on *De agricultura* by Rutilius Taurus Palladius (late AD 300s). Book VII is "the best general work on agriculture since Columella [mid-first century AD] and shows how scientific thinking was stirred by the current technical changes in agriculture" (Morton 1981:93).



Albert was the only medieval encyclopedist who added significant observations of his own to supplement what he culled from his sources (Paszewski 1968, Stannard 1978, 1980*a*, *b*, Reeds 1980, Egerton 1983). Book VI contains most of his personal observations and is the book most extensively translated into a modern language (Albertus Magnus 1992). He believed that wheat and rye change from one species to the other, depending upon the soil in which the seeds are planted (Sprague 1933:432). His account of oak trees includes these observations and speculations on oak galls (Grant 1974:700):

> *On the leaves of the oak often grow certain round ball-like objects called galls, which after remaining some time on the tree produce within themselves a small worm bred by the corruption of the leaf. If the worm exactly reaches the midst of the gall apple, weather prophets foretell that the coming winter will be harder; but if it is near the edge of the gall, they foretell that the winter will be mild.*

Albert's *De vegetabilibus* was the most important botanical work of the Middle Ages (Thorndike 1923:538–539), yet it does not equal the botanical treatises by Theophrastos (c.371–c.287 BC), which he never saw.

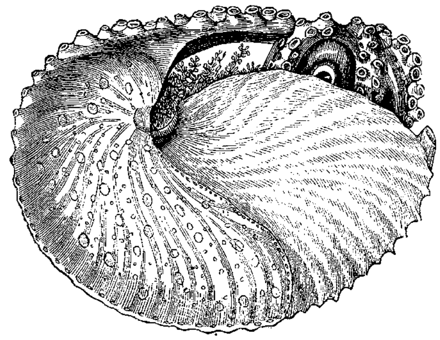
Albert's *De animalibus libri XXVI* was his most extensive and influential work, probably begun between 1256 and 1260. It is organized into three parts: books I–XIX paraphrase and explain the zoological works of Aristotle translated from Arabic by Michael Scot; books XX–XXI are Albert's additions to Aristotle—his most original contribution—and books XXII–XXVI are, translators Kitchell and Resnick admit, a bestiary "based on *De natura rerum* of his former student, Thomas of Cantimpré" (1999:40), although this is not acknowledged on the title page. Albert's use of Thomas's work deserves more than passing mention. Thomas (1201–1270/1272) was also of aristocratic birth, born at Lewes, near Brussels. He studied at Liège, 1206–1216, and then entered the Augustinian abbey at Cantimpré. In 1232, Thomas transferred to the Dominican Order and went to study under Albert at Cologne, 1233–1237; finally he studied at the University of Paris, 1237–1240. While at Paris, he completed his encyclopedia, *De naturis rerum*—the first encyclopedia of all natural phenomena in Latin since the *Naturalis historia* by Pliny (c. AD 23–79) (Ley 1968:92). Thomas was not a scholar like Albert, but rather a teacher who compiled popular scientific information for preachers to use for religious arguments in their sermons (Friedman 1974:107–110, Kibre 1976). Nevertheless, Albert borrowed without acknowledgment most of this work's bestiary (Thomas of Cantimpré 1973:101–311) for his own books XXII–XXVI. M. Bormans published this fact in 1852, and it was subsequently accepted by several other scholars. The philologist Hermann Stadler (1906), however, contested this claim before publishing his edition of Albert's Latin text (Albertus Magnus 1916–1921). There matters stood in 1931, when Pope Pius XI elevated Albert to the status of saint and doctor of the Church. Later, however, Pauline Aiken reexamined the matter and concluded that Stadler's article "is a tissue of errors" (1947:206). Aiken summarized her detailed findings (1947:225):

Albertus describes four hundred seventy-six specific creatures. For four hundred of these (more than five sixths of the total number) Thomas is the main source. In three hundred seventy-four of these descriptions (nearly four fifths of the total) there is either no supplementary material or not more than a few sentences per section.

Because Albert cited both ancient and Arabic sources, but not his contemporary Latin source, it is difficult to avoid the conclusion that he intentionally plagiarized from his former student. We are obliged to rectify the credits, but the influence of Albert's *De animalibus* justifies taking seriously this composite work. In their excellent translation of *De animalibus*, Kitchell and Resnick (1999) do not distinguish, in books I–XIX, between Albert's paraphrase of Aristotle and Albert's own additions (although this is often indicated in their notes), and their example is followed here. That distinction, however, is made in Stadler's edition (Albertus Magnus 1916–1921). Next after his use of the works of Aristotle and Thomas, the third most important source for Albert seems to have been *De animalibus* by Ibn Sina (Avicenna, 980–1037), which, like Aristotle's zoology, had been translated from Arabic into Latin by Michael Scot.

The combined text and notes of Kitchell and Resnick's translation (Kitchell and Resnick 1999) are 1720 pages (Stadler's compact Latin text and notes [Stadler 1906] are 1598 pages)—too long for an adequate summary here of discussions having ecological interest—yet it is possible to indicate their character and scope (as Balss did in greater detail [1928:75–130], but not reprinted in Balss [1947]). The translators' introduction (Kitchell and Resnick 1999) emphasizes Albert's skepticism of many fabulous reports in the scientific literature, his insistence upon natural, rather than supernatural, explanations, and the many first-hand observations that he reported (Kitchell and Resnick 1999:36–42). This is all true, and is why his *De animalibus* is of lasting interest. However, it is also true that there were limits to his ability to discriminate, and there were reports, which he accepted, that are no longer credible.

Books I–IV are on the anatomy and physiology of animals and humans, topics only indirectly relevant to ecological sciences, but it is interesting methodologically to follow his attempt to determine whether Aristotle is correct in saying that veins and arteries both arise at the heart, or Galen is correct in saying that veins arise at the liver and arteries at the heart. The answer presumably had important implications for physiology. To resolve the matter, Albert not only discussed the arguments of both men, he also brought in those of Ibn Sina and Ibn Rushd (Averroes, 1126–1198). Albert believed that he then could reach a conclusion "by use of reason and solid experiential knowledge that is completely trustworthy" (Tilmann 1971:351). He concluded that Aristotle was correct, but he did so by using Aristotelian logic. If he based any of his arguments upon his own observations, he failed to say so, and "the solid experiential knowledge" that he referred to apparently was obtained by Ibn Sina and Ibn Rushd.



Books V–VI are on animal reproduction and books IX–X are on human reproduction. He accepted the Aristotelian idea that some animals are created from mud, putrescence (Tilmann 1971:516), slime, or sand, and "they differ to the extent that the slime or sand from which they are generated differs" (Tilmann 1971:518–519). After a survey of the reproduction of oceanic nonfish animals [invertebrates], however, he acknowledges that "It is not possible to know the differences in generation of all these animals well, because the experts can scarcely observe the times of the conception, egg laying, and emergence of the young of these animals" (Tilmann 1971:524). He mentions the fact that different species of birds lay different numbers of eggs without much speculation as to why. For eagles, however, he reported that they lay three eggs but only raise two chicks, and does offer an explanation: "Some say the reason for this is that it is so weakened by incubating the eggs that it cannot hunt enough chicks of other birds for three and is scarcely able to care for two of them" (Tilmann 1971:545).

In book VIII, "On Animals' Habits," Albert added this to Aristotle's discussion of hawks and eagles (Tilmann 1971:599):

Of all the genuses of eagle and falcon, the best and the fiercest is the one which comes from the northern region of Sweden and Latvia whose latitude is more than fifty degrees from the equator. These are fierce birds and they would rather eat fish than flesh. Thus, certain astures which were brought from that land to our land all catch birds to be sure, but they eat crabs more readily than any other food. These astures are held by the falconers in our land to be better and nobler than any others, and they are very large. One who is quite an expert said to me that even in that land the eagles mostly feed on fish and that eels and fish are thus found in and near their nests.

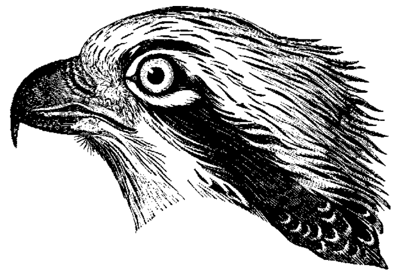
Albert's discussions of hawks and falconry have been closely studied, including his sources. We know that he borrowed from Thomas of Cantimpré, but did he also have access to Frederick II's *De arte venandi cum avibus*? Apparently not: "it seems more likely that Albert was transmitting information passed on to him orally by Frederick's falconers" (Oggins 1980:444). Regardless of his sources, Albert's discussion seems generally well informed. However, it also includes this folklore: "There is in our land, also a small genus of eagle called the fish-eagle [osprey]. It hunts only fish and has one webbed foot, for swimming, like that of a goose, while the other foot has hooked talons for seizing, like that of an eagle" (Tilmann 1971:599).

Albert was widely traveled in Europe (maps: Kitchell and Resnick 1999:7, 9, Tilmann 1971:19), and this experience may have both increased his interest in migrations and also added to his knowledge of it. He knew that heat or cold that was healthful to some species could be harmful to others. He thought that migration was due either to heat (in spring) or cold (in autumn), although he knew of various ways in which animals responded to changes in climate (Tilmann 1971:613):

> *Of those animals which do go away, some go to elevated places, seeking in them a temperate cold. Others, however, go to cave-like, warm places, seeking warmth in them. They hide themselves away in the same places—in hollows in trees or beneath drooping leaves or in actual caves—seeking heat. Some do not change place. In our lands the cranes are present continuously in winter and summer. Still, our dwelling place is very cold, being almost 47 degrees of latitude from the equator.*

Geese bred in Sclavia at "moist, sandy, marshlike places," but at the beginning of winter they "come back to our land," which he said was at a latitude of 47º, seeking "food and the more temperate air" (Tilmann 1971:613). They fly south on winds from the north, in flocks of thousands. Fish either migrate or seek out holes for the winter. "Some fish move from the depths of the sea during the winter and come near the land's edge in search of heat. Others do the opposite and flee the shore for the depth of the sea, escaping the shore's heat" (Tilmann 1971:614). Albert also claimed that when animals migrate from a warm to a cold place, they fatten, but when they return they grow thin "because of the dissolving and consuming heat" (Tilmann 1971:615).

Discussions of differences between the sexes were susceptible to gender bias and/or folklore, and Albert succumbs to some of those reports. He reported that, in general, females are easier to train than males, and this is especially true among dogs (Tilmann 1971:668). Among quadrupeds, females are weaker than males, but in birds of prey females are the larger and stronger sex. A female bear "has boldness due to the bad habits which are attendant upon her sex" (Tilmann 1971:669). Females of almost all species "are fiercer than the males during the time in which they have young." As for humans, he cited Ibn Sina to the effect that women are "stupider when it comes to honest and good things, and to governance" (Tilmann 1971:669). Presumably, he wrote only for male readers, because it did not seem necessary to support this claim with evidence. Moving on to mating, he reported that pigeons remain faithful to each other after mating, but that Ibn Sina saw two males fight over a female, which accepted the winner, but when the loser returned to fight again and this time won, the female accepted him instead. After copulation, "the female follows the male and obeys him. When, however, the female does not come into the nest quickly the male beats her with his wings" (Tilmann 1971:689). However, even on sexual matters, there were limits to what Albert could believe. He could believe that a female turtledove remained faithful to her mate during his lifetime, but not afterwards: "Some say that even after the death of this one she does not take another husband, but this is neither probable nor has it been verified through experience" (Tilmann 1971:690).



Albert was the outstanding encyclopedist of the High Middle Ages (1000–1350); *De natura locorum* was first printed in 1514, *De vegetabilibus* in 1517, and *De animalibus* in 1478. There were other encyclopedists whose works were as widely or more widely read than his. At best, all of their encyclopedias blended fact and folklore, and Albert's had the most first-hand information. There was no simple progression toward greater and greater accuracy from one to the next. Like Islamic civilization, medieval Europe suffered a catastrophe and decline; the Black Death struck in 1347 and continued, off and on, for several centuries. It is generally understood to have been bubonic plague, although recent scholarship suggests that the original epidemic might not have been limited to just one type of infection (Cantor 2001:part I). Unlike Islamic civilization, however, Europe rebounded a century later, stronger than ever. The survival of universities and Gutenberg's invention of the printing press were important factors in that recovery.

Acknowledgments

I thank Anne-Marie Drouin-Hans, Université de Bourgogne, and Jean-Marc Drouin, Musée Nationale d'Histoire Naturelle, for their suggestions.

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Normality of Raw Data in General Linear Models: the Most Widespread Myth in Statistics

In years of statistical consulting for ecologists and wildlife biologists, by far the most common misconception we have come across has been the one about normality in general linear models. These comprise a very large part of the statistical models used in ecology and include *t* tests, simple and multiple linear regression, polynomial regression, and analysis of variance (ANOVA) and covariance (ANCOVA). There is a widely held belief that the normality assumption pertains to the raw data rather than to the model residuals. We suspect that this error may also occur in countless published studies, whenever the normality assumption is tested *prior* to analysis. This may lead to the use of nonparametric alternatives (if there are any), when parametric tests would indeed be appropriate, or to use of transformations of raw data, which may introduce hidden assumptions such as multiplicative effects on the natural scale in the case of log-transformed data.

Our aim here is to dispel this myth. We very briefly describe relevant theory for two cases of general linear models to show that the residuals need to be normally distributed if tests requiring normality are to be used, such as *t* and *F* tests. We then give two examples demonstrating that the distribution of the response variable may be nonnormal, and yet the residuals are well behaved. We do not go into the issue of how to test normality; instead we display the distributions of response variables and residuals graphically.

A very brief theory of general linear models

We present two simple examples from among the large class of general linear models, which encompass such methods as, e.g., the *t* test, simple and multiple linear regression, polynomial regression, ANOVA, and ANCOVA. In every case, a response variable is thought to be composed of additive systematic components and one or several random components. The latter are usually assumed to be from a common normal distribution with a constant variance.

Simple linear regression

The normal error regression model for a sample of size *n* that links a response variate *Y* to one continuous explanatory variable *X* is as follows (from Neter et al. 1990:52):

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

where Y_i is the observed response for the *i*th unit; X_i is the value of the explanatory variable for the *i*th unit; β_0 and β_1 are parameters, i.e., unknown constants to be estimated from the data; ε_i are independent $N(0, \sigma^2)$, i.e., independent normally distributed residuals about a zero mean with constant variance σ^2; $i = 1,\ldots, n$ and indexes the units.

Normality and homoscedasticity (constant variance) of residuals is not necessary to use the least-squares or maximum-likelihood method to provide unbiased point estimates of the parameters β_0 and β_1. However, to provide significance tests or confidence intervals, the standard assumption of a normal distribution of error terms ε_i needs to be invoked (Neter et al. 1990).

One-way ANOVA

The linear additive model links a response variate *Y* to one discrete explanatory variable with *I* levels (discrete values) and can be written as (from Steel and Torrie 1980:149):

$$Y_{ij} = \mu + \tau_i + e_{ij}$$

where Y_{ij} is the observed response for the *j*th unit in group *i;* μ and τ_i are unknown constants, i.e., parameters to be estimated from the data; μ is the overall mean response and τ_i is the additive effect of level *i* ($i = 1,\ldots, I$); e_{ij} are independent random components; $j = 1,\ldots, n$ and indexes the units within each level of the explanatory variable.

Again, when significance tests or confidence intervals are desired, distributional assumptions about the random components e_{ij} need to be made. Customarily, they are assumed to be independent normally distributed with zero mean and constant variance σ^2.

Two numerical examples

Multiple linear regression

The number of fruits per stem of *Gentiana cruciata*, a rare plant of calcareous grasslands, had been measured on 810 plants and ranged from 1 to 60. The distribution of these data was clearly not normal, but right skewed (Fig. 1a). A multiple-regression model using three continuous explanatory variables (population area, number of stems per plant, and length of the longest stem) fit by the package Genstat (Payne et al. 1993) accounted for 47% of the variance in the data. It showed that the response variable was significantly and positively related to all three explanatory variables. The residuals of this model were reasonably close to a normal distribution (Fig. 1b). These data are from a larger study on a rare plant and its specialist herbivore. (For further description of the system, see Kéry et al. 2001.)

One-way ANOVA

We then generated 200 data points for each of four populations. Think of it as the mean number of seeds per fruit of *Gentiana cruciata*. Mean numbers of seeds were 100, 200, 300, and 400 in the four populations, respectively. Normally distributed noise with variance 50 was added. The distribution of these data was again far from normal (Fig. 1c). However, when the systematic popula-

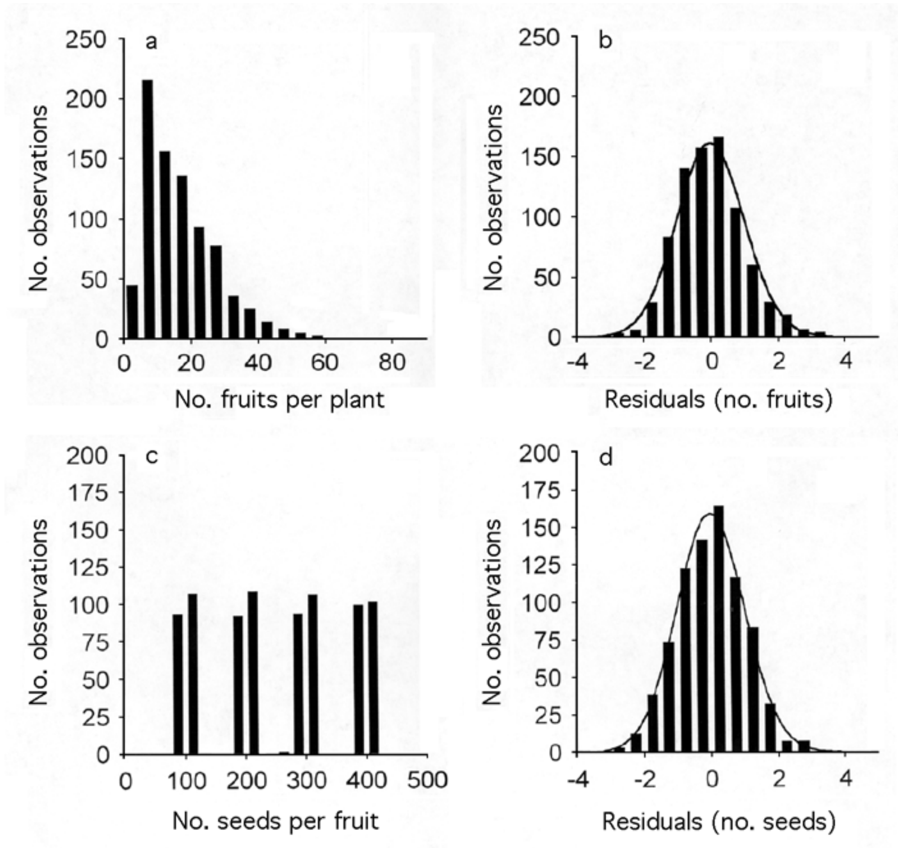

Fig. 1. Distribution of the raw data and of the residuals (a,b) for a multiple linear regression analysis, and (c,d) for a one-way analysis of variance.

tion effect was taken out by fitting one discrete explanatory variable, the resulting residuals were normally distributed (Fig. 1d), as would be expected in this simulated case.

Conclusions

There is a very widespread misconception that, in general linear models, the raw data instead of the residuals of a model have to be normally distributed to permit construction of confidence intervals and significance statistics. Here we state this to be false and give two examples that show raw data may have some other distribution, and yet the residuals of a linear model turn out to be reasonably close to a normal distribution. Such examples abound, and we think that only in a minority of cases are the raw data already clustered symmetrically around a single mode. Residual analysis for linear models is easily conducted in the two statistical packages that we are familiar with, Genstat (Payne et al. 1993) and SAS (SAS 2001). Residuals are easily stored in each analysis and then examined visually, e.g., by histograms or plots, or by formal statistical tests for normality. There is a large literature on model checking, also called model criticism, in general linear models (e.g., Cook and Weisberg [1982], Atkinson [1985], and also general texts on regression such as Draper and Smith [1981], or Neter et al. [1990]). Model criticism is an important part of any statistical modeling. In summary, we hope that this note is a contribution toward better statistical practice by doing away with the myth of normality of the raw data in general linear models.

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