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Beeswax exports and rainfall in the savanna woodlands of east central Africa

HR Hepburn *, SE Radloff

Departments of Zoology and Entomology and Statistics, Rhodes University, PO Box 94, 6140 Grahamstown, South Africa

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Summary — Time series and regression analyses of rainfall and beeswax exports from the woodland savanna of east central Africa establish that these two variables are most significantly and highly correlated when phase-lagged by one bee year, running from July to June of the following year. Rainfall and honey production are also highly significantly correlated when lagged by one bee year. However, honey and wax production are highly correlated on a same bee year basis. Thus beeswax harvest of any one year depends on the rainfall of the previous bee year. This is consistent with general effects of climate on vegetation and, specifically with the fact that the bee-trees of the miombo flower in the dry season.

***Apis mellifera* / beeswax exports / rainfall / savanna woodland**

INTRODUCTION

Beeswax exports from Africa, about half of recent world trade tonnage (Crane, 1990), stem from the 17th century (Parent et al, 1978). The trade persists because wax is largely imperishable and inflation-proof against local currencies (Roberts, 1970; International Trade Centre, 1978). Beeswax has few traditional uses in Africa, it is simply the by-product of a honey-hunting culture (Irvine, 1957; Ntenga and Mugongo, 1991).

The climate and flora of the savanna woodlands of east central Africa are favourable for beeswax production because temperatures are seldom low enough to induce dormancy in the vegetation (Walter, 1976; Cole, 1986) and rainfall largely governs flowering intensity (Hepburn and Radloff, 1995). Because of the nature of flowering cycles in the savanna woodland, a link between rainfall and the beeswax harvest has long been mooted but never tested biologically and statistically (Harris, 1932;

* Correspondence and reprints

Smith, 1951, 1994; Sheriff, 1963). This report provides the results of such tests.

MATERIALS AND METHODS

Three different data sets were evaluated. Data set 1 is the annual metric tonnage of beeswax exports for the period 1936-1961 from Tanzania and Zambia (Sheriff, 1963) and Kenya (Kenya, 1967) and the corresponding rainfall data from the World Weather Records (1934-1968). Data set 2 is honey production and beeswax exports, in decade classes, for the period 1906-1985 for Tanzania (Ntenga and Mugongo, 1991).

No precise data on annual honey production matched for rainfall is available for a specific apiary and locality in the above countries for the period of survey. The best available approximation is a scale hive and rainfall data set from a woodland savanna apiary at Duiwelskloof (23°37S, 30°10E) in the northern Transvaal of South Africa for the period 1932-1938. This is data set 3 as follows: 1932-1933, rain 527 mm; 1933-1934, rain 963 mm, honey 38.1 kg; 1934-1935, rain 433 mm, honey 80.4 kg; 1935-1936, rain 481 mm, honey 23.2 kg; 1936-1937, rain 749 mm, honey 30.0 kg; 1937-1938, rain 532 mm, honey 63.0 kg; 1938-1939, honey 37.2 kg.

All data were plotted in bee years running from July to June because this is the seasonality of the annual cycle of honeybee colonies in savanna woodland areas below the equator. Also, the historical record clearly shows that beeswax is almost always (>90%) harvested during the mid-year dry season (Estève, 1932; Harris, 1932; Irvine, 1957; Sheriff, 1963). The relevant honeybee races would have been mainly *A m adansonii* and *A m scutellata,* but it is not possible to specify their possible contributions to the production figures.

Both the rainfall and beeswax export data series exhibited significant seasonal autocorrelations which had to be removed before any correlation between the two time series was undertaken (Box and Jenkins, 1976). This is because the presence of seasonal autocorrelation can lead to spurious significant correlation results. A standard method for removing seasonal correlation is to fit a suitable low-order auto-regressive model called a Box-Jenkins model to both time series. The uncorrelated so called 'white noise' residuals are then computed for each series by subtracting the fitted auto-regressive model from the original time series (Box and Jenkins, 1976).

Rainfall and beeswax export data were initially standardised for each country by calculating the difference between the observed value in any bee year and the mean value for that country, divided by the standard deviation. Box-Jenkins (1976) time series models were fitted to both the rainfall and change in beeswax export indices for each country separately and the resulting white noise residuals were cross-correlated with the rainfall residuals lagged for 12 bee years to obtain the best correlation. The rainfall and change in beeswax exports indices for the three countries were then combined and the time series procedures repeated.

RESULTS

When data set 1 on beeswax exports from Kenya, Tanzania and Zambia was analyzed, cross-correlations between changes in beeswax exports and rainfall were found to be largest when rainfall was lagged by one bee year (fig 1). The corresponding correlation coefficients were as follows: Kenya, $r = 0.43$ and $P = 0.0157$; Tanzania, $r = 0.46$ and $P = 0.0016$; Zambia, $r = 0.36$ and $P = 0.0525$ (not significant); for all three countries combined, $r = 0.41$ and $P = 0.0001$. Thus, beeswax exports from these savanna woodland countries are highly significantly correlated with rainfall lagged by one year (fig 1).

Because wax secretion is driven by honey metabolism and comb building by space needs for brood rearing and the storage of surplus honey (Hepburn, 1986) a honey-wax correlation is expected. The link between honey production and wax exports was investigated in data set 2 from Tanzania for the period 1906-1985, which yielded a highly significant correlation ($r = 0.98$, $P < 0.0001$).

Finally the correlation between rainfall and honey was investigated for a specific apiary. A linear regression analysis of rainfall and honey yield at Duiwelskloof (data set 3) yielded a significant correlation coefficient $r = 0.99$ with $P < 0.0001$ when these two variables were lagged by one bee year.

There remain two problems of human origin to resolve: relative harvest effort and export constancy. Taking the latter first, for the period 1936–1985, an estimated average of 70 ± 3% of beeswax produced in Tanzania was actually exported (Sheriff, 1963; Ntenga and Mugongo, 1991) so that export level is a constant for purposes of this discussion. As to relative harvest effort for the period 1916-1985 (Ntenga and Mugongo, 1991) the resulting curve is a squat parabola for which there is (1) a linear increase in exports at 1% per annum for 1916-1945; (2) no change for 1946-1965; and (3) a linear decrease in exports at 1% per annum for 1966-1985. The seven decade trend reflects harvest success; but the inter-annual variations remain intact (fig 1). This is analogous to spot price variation and long term trends in commodity trade where annual export is the spot price and the long term trend the harvest effort over decades.

DISCUSSION

Analysis of the rainfall and beeswax export patterns from the woodland savanna of east central Africa showed these variables to be most significantly correlated when lagged by one bee year, providing firm support for the primary hypothesis. Likewise, variations in the human harvest efforts can be readily accommodated with these conclusions. Thus, from one bee year to the next, the size of the beeswax crop in the woodland savanna depends on the rains of the previous bee year.

The rainfall-beeswax correlation simply means that this bee year's rainfall determines the size of next bee year's wax crop (at least for the period 1936–1961). In a biological context this relation is likely to be based on the chain of causal relationship rainfall - flowering - honey storage and wax

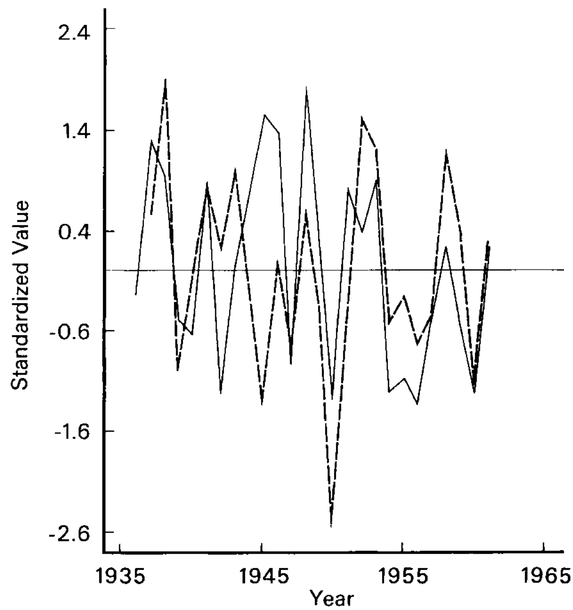

Fig 1. Time sequence plot of standardised total annual beeswax export and rainfall data from Kenya, Tanzania and Zambia from 1936 to 1961. (Rainfall data has been lagged by one year). Solid line = beeswax export, broken line = rainfall.

production. While it can be regarded as self-evident that flowering equates to nectar the relative amounts of which would be reflected in the annual honey harvest, the strong correlation between rainfall and honey harvest, also lagged by one bee year, as well as the same-year correlation between wax export and honey production corroborate this causal chain. Thus, the original rainfall-beeswax hypothesis acquires real biological meaning given the significant correlations for honey-wax and rainfall-honey.

At first sight these relationships may seem biologically counter-intuitive from a temperate zone perspective as opposed to one from subequatorial Africa. The difference lies in the relative importance of temperature for the former and rainfall for the latter. Detailed meteorological studies of honey production in the northern temperate zone unequivocally demonstrate the overriding importance of ambient temperature in colony performance (Hambleton, 1925; McLellan, 1967). Similarly the constraints of temperature on the onset of comb building have been well documented (Koch, 1961).

It has already been noted that temperatures in the savanna woodlands of Africa do not drop low enough to induce dormancy in the vegetation (Walter, 1976; Cole, 1986). For the greater part of Africa the crucial determinant for vegetation is water (van Chi-Bonnardel, 1973). In fact, the diversity and abundance of the flora varies with rainfall (White, 1983; Cole, 1986). The most important cause of the delay between rainfall and honey crop, however, is that the majority of the trees on which honeybees depend tend to flower in the dry seasons (Silberrad, 1976; Lobreau-Callen, 1987; Hepburn and Radloff, 1995) and, as shown above, the extent of flowering (measured in honey and wax yields) is correlated with the rainfall of the previous year's rainy season.

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Résumé — Exportations de cire d'abeille et précipitations dans la savanne arborée de l'est de l'Afrique centrale. L'hypothèse selon laquelle les exportations de cire d'abeille d'une année donnée dépendent des précipitations de l'année précédente pour une savanne arborée ouverte (miombo) dans l'est de l'Afrique centrale a été proposée il y a plus de 60 ans mais n'a jamais été testée. La production de cire par les abeilles mellifères (*Apis mellifera* L) est déterminée par la récolte de nectar, qui dépend elle-même des précipitations par l'intermédiaire des floraisons. Aussi, pour tester l'hypothèse, nous avons étudié les corrélations possibles entre les variables pertinentes. Les analyses de séries temporelles et de régression portant sur les exportations de cire d'abeilles et les précipitations, pour le Kenya, la Tanzanie et la Zambie sur la période 1936-1961, ont montré une corrélation hautement significative (r = 0,41, P = 0,0001) entre les variables lorsqu'elles sont considérées sur une année apicole (de juillet à juin de l'année suivante) (fig 1). De même, les précipitations et la production de miel sur la période 1932–1938 pour un rucher donné dans la partie boisée de l'Afrique du Sud sont significativement corrélées lorsqu'on les considère sur une année apicole (r = 0,99, P < 0,0001). Il existe également une corrélation hautement significative pour une même année apicole entre la production de miel et les exportations de cire pour la Tanzanie sur la période 1906-1985. Les variations dans l'activité humaine de récolte ont une action que l'on peut considérer comme négligeable sur la relation récolte de cire d'abeille-précipitations. L'hypothèse de départ, selon laquelle la récolte de cire d'une année dépend des précipitations de l'année précédente, est donc fortement confirmée par une suite de relations causales. Elle est cohérente avec le fait qu'en Afrique la principale contrainte pour la végétation est l'eau, et non pas la température, et que la floraison pendant la saison sèche de la majorité des arbres du miombo, sur lesquels les abeilles vont butiner, dépend des précipitations de la saison humide de l'année précédente.

***Apis mellifera* / cire d'abeille / exportation / précipitation atmosphérique / savanne arborée**

Zusammenfassung — Bienenwachsexport und Niederschlagsmengen in den Savannenwäldern des östlichen Zentralafrika. Seit über 60 Jahren wird die Hypothese vertreten, daß die jährlichen Bienenwachsexporte aus den offenen Savannenwaldgebieten (Miombo) des östlichen Afrikas von der Niederschlagsmenge des vorhergehenden Jahres bestimmt sind. Da die Wachssekretion vom Nektareintrag bestimmt wird und damit über das Blütenangebot von der Niederschlagsmenge abhängt, wurden zur Überprüfung des Zusammenhangs mögliche Korrelationen der relevanten Variablen untersucht. Zeitreihen- und Regressionsanalysen von Daten über den Wachsexport und die Niederschlagsmengen in Kenia, Tansania und Sambia im Zeitraum von 1936-1961 ergaben eine hochsignifikante Korrelation (r = 0.41, P = 0.0001) zwischen diesen Variablen, wenn sie um ein Bienenjahr (1. Juli bis 31.Juni des folgenden Jahres) versetzt wurden (Abb 1). Die Niederschlagsmengen und die Honigproduktion auf einem Bienenstand im südafrikanischen Waldgebiet im Zeitraum von 1932 bis 1938 waren bei zeitlicher Versetzung um ein Bienenjahr in ähnlicher Weise signifikant korrelliert (r = 0.99, P < 0.0001). Ebeso ergab sich eine auf das gleiche Jahr bezogene signifikante Korrelation (r = 0.98, P < 0.0001) zwischen der Honigproduktion und den Bienenwachsexporten in Tansania im Zeitraum von 1906 bis 1985. Die Auswirkungen von unterschiedlicher menschlicher Ernteaktivität auf den Zusammenhang zwischen Bienenwachsernte und Niederschlagsmenge können als vernachlässigbar angesehen werden. Die eigentliche Hypothese, daß die Wachsernte von der Niederschlagsmenge des Vorjahres bestimmt wird , wird daher durch eine Folge von kausalen Zusammenhängen gestützt. Diese steht zudem mit der Tatsache im Einklang, daß die Vegetation in Afrika hauptsächlich durch die Wasseversorgung und nicht die Temperatur eingeschränkt ist. Sie wird weiter dadurch erkärt, daß die Blütezeit des überwiegenden Anteils der Bäume, von denen die Bienen Nektar gewinnen, in der Trockenzeit stattfindet und damit von der Niederschlagsmenge in der vorjährigen Regenzeit abhängt.

Honigbienen / Bienenwachsexport / Niederschläge / Savannenwälder

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