Scientific Note

A scientific note on the 'Liebefeld Method' to estimate honey bee colony strength: its history, use, and translation

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The strength of honey bee (*Apis mellifera*) colonies is vital for successful beekeeping. This parameter influences the amount of honey produced (Farrar 1937) and the number of foragers available to perform pollination services (Harbo 1986; Szabo and Lefkovitch 1989; Liebig 1993; Keller et al. 2005) and reflects its health and fitness (Imdorf et al. 2010; Dainat and Neumann 2013). Thus, there is a need for beekeepers and researchers interested in colony performance and vitality to have a reliable tool for measuring colony strength and development over time. Determining the status of a colony (i.e. healthy and productive or weak) requires the counting of thousands of highly mobile adult insects, of larvae lodged at the bottom of wax cells and of cells containing food stocks. A method allowing for such estimations was first described in 1987 in *Apidologie* in German. Here, we describe the history and principles of this easy, cost-efficient, reproducible and standardized field method that improved previous procedures and which later became known as the 'Liebefeld Method'. This method rapidly delivers reliable data on a large number of colonies, which is an advantage for beekeepers and researchers who require a large amount of high-quality field data. Although it has been widely used, the original language of the publication describing the estimation procedure likely reduced its international impact. Due to the continued relevance of this method today, the original article has been translated into English, and the citable article (DOI https://doi.org/10.5281/zenodo.3341580) is now freely available in a repository with permanent access (https://zenodo.org/record/3341580).

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1. QUANTIFYING COLONY STRENGTH

Researchers have long been interested in understanding the population dynamics of honey bee colonies. In 1850, the German entomologist August von Berlepsch quantified the number of eggs a healthy queen could lay and reported a maximum fecundity of 1200 eggs per day (Berlepsch 1873). More than a century later, between the 1960s and the 1980s, Gerig, Imdorf,

Wille, and co-workers developed a method to easily and rapidly quantify colony strength (i.e. the number of adult workers and amount of brood and food storage cells) by visual estimation in a standardized manner (Imdorf et al. 1987). This method was later named the Liebefeld Method after the town in Switzerland where the authors' honey bee research institute was located. Testifying of the acceptance and common use of the method, German apidologist created the verb 'liebefeldern' to designate the action of estimating colony strength.

2. USE OF THE LIEBEFELD METHOD OVER TIME

From the 1960s onward, the Liebefeld Method was routinely used at the Swiss Bee Research Centre (Wille 1967; Wille and Gerig 1976) to study colony development (i.e. demographical changes over time), food storage dynamics, brood production and the lifespan of adult workers, in addition to the influence of the location of apiaries and of farming practices on honey bee health (Charrière et al. 2010; Gallot et al. 2016). Researchers also utilized this method to evaluate the effect of *Varroa destructor* control measures (e.g. drone removal, colony splitting, formic and oxalic acid treatments) on colony development (e.g. Imdorf et al. 2010). Shortly after its publication, other German-speaking honey bee research institutes adopted the Liebefeld Method in studies of the impact of beekeeping practices and disease-control on colonies (Kovac 1988; Büchler 1992). Later, the method was applied to similar research topics in many countries (e.g. Pietropaoli and Formato 2017; Kovačić et al. 2018; Lodesani et al. 2019; Osterman et al. 2019), as well as in a large-scale pan-European study that compared colony development in different climatic regions and investigated genotype/environment interactions (Büchler et al. 2014). Furthermore, the Liebefeld Method was used as the basis to design the standard method to estimate colony strength in the *BEEBOOK* (Delaplane et al. 2013). Multiple citations in scientific journals (CrossRef, $n = 55$; Web of Science, $n = 72$; Google Scholar, $n = 105$, accessed 24/05/19) attest of the use and usefulness of the Liebefeld Method. However, the number of

Table I. Extract of field sheet for recording colony strength data, including both faces (a and b) of each comb, in a hive with one brood chamber and one super

	Brood chamber						Super						
Beekeeper													
Apiary													
Colony													
Date/Time													
Hive type													
Observations							Weather						
							Flight activity none low medium high					Observation	
	Adult workers						Adult workers						
Start L	dm^2	closed brood	open brood	drone brood	Pollen	Honey	dm^2	closed brood	open brood	Pollen	Honey		
R													
Frame													
1a													
1b													
2a													
2b													
3a													
3b													

To estimate the number of adult workers, one estimates the ratio between total surface area of a comb face and the surface area covered by adult workers. One then multiplies the maximum number of adult workers occupying a comb face (e.g. 1400 on Dadant-sized combs) by this ratio. Amount of brood and food reserves are given as the number of estimated decimetre squared covered and are therefore valid irrespective of comb format. Other columns can be added for surface areas that are covered by pollen or honey stores, depending on the user's interest

citations is relatively low for a two-decade old article, which is certainly due to its original publication language. To make this method more broadly available, we have provided a freely accessible and citable translation of the original article in English (https://zenodo. org/record/3341580).

3. PRINCIPLES OF THE LIEBEFELD METHOD

The Liebefeld Method is based on a visual estimation of the number of adult workers covering each comb side and beneath them, of the surface area (dm^2) of the comb that is occupied by the open brood, capped brood, honey and pollen stores. The number of adult workers is estimated in absolute values rather than square decimetres to adjust, in real time, for variable worker density on a comb (i.e. workers in overlapping layers or with their bodies in cells). The data can be recorded either on paper or in a digital field sheet (Table I and Supplementary File 1). Table II indicates, for different frame formats, the total surface area of one side of a comb and the maximum number of adult workers that can occupy it. A spread sheet with automatic conversion of comb surface to the number of cells according to their width is available in Supplementary File 1.

4. TRAINING

An online module based on 108 images of Dadant Blatt and Swiss-type combs with known numbers of adult workers allows users to practice the Liebefeld Method with a low logistical investment. The module is available on the website of the Swiss Bee Research Centre (www.agroscope.admin.ch/liebefeld-training). However, regular calibration is required to accurately associate the users' estimates to the absolute number of adult workers on combs. The latter can be achieved by brushing all the honey bees into a box and weighing them after population estimation in the field (Imdorf et al. 1987). The accuracy of experienced users' estimations of adult worker population sizes exceeded 96% (Imdorf et al. 1987). Calibration for brood estimations can be performed by subdividing an empty frame into square decimetres with strings and superimposing it on the comb under scrutiny (Imdorf et al. 2010). The accuracy of capped brood estimation was high (99%), whereas the accuracy of open brood estimation was lower (65%) (Imdorf et al. 1987).

5. ADVANTAGES AND LIMITATIONS OF THE LIEBEFELD METHOD

Without the need to remove workers from the combs, the Liebefeld Method is simple and fast. An experienced observer spends approximately 10 min per colony kept in an 11-frame Dadant Blatt hive. The method thus allows the strength of many colonies in the field to be estimated in a single day. Application of the method every 3 weeks, which is the developmental period of an *Apis mellifera* worker, enables accurate quantification of a colony's

Table II. Reference values for the estimation of adult workers covering combs of different hive types according to Imdorf et al. (2010) (based on wax foundation sheet size)

Comb type	Surface (dm^2) per face of a hive body comb	Surface (dm^2) per face of a super comb	Worker counts per face of a hive body comb
Swiss type	8.5	4	1200
Dadant Blatt	11	5.5	1400
German norm	7	7	900
Deep Langstroth	8.5	4.5	1100
Zander	7.5	7.5	1000

demographic dynamics (Bühlmann 1985). Although the method is mildly invasive due to repeated colony opening and frame extraction, it has no measurable negative effects on colony development (Imdorf et al. 1987; Imdorf and Maquelin 1993; Liebig 1994). Contrary to the belief of many beekeepers, colony strength can be estimated in spring or autumn, when temperatures range between 10 and 15 °C, without negatively affecting colonies (Imdorf and Maquelin 1993).

Colony strength estimations performed late in the honey bee season when resources decrease can trigger robbing. This problem can be reduced by physically restricting the opening through which combs are taken out of the colony or by working under a tent. Estimating the colony strength early in the morning or late in the day can also reduce the likelihood of robbing. Liebefeld estimations performed before or after the honeybees leave the hive capture the total number of adults in a colony. However, in large experiments, it is not feasible to evaluate all colonies when the foragers are still in the hives. In such cases, the daily variations of external factors affecting foraging activity, such as excessive heat or bad weather, can be evened out by alternating the colonies estimated between experimental groups (Imdorf et al. 2010).

6. OTHER METHODS FOR ESTIMATING COLONY STRENGTH

During the past 25 years, other methods for estimating colony strength have been developed (Burgett and Burikam 1985; Marchetti 1985; Skinner et al. 2001; Gris 2002; Delaplane et al. 2005; Delaplane et al. 2010; Guzman-Novoa et al. 2011; Avni et al. 2014). These are based on the same general principle as that of the Liebefeld Method (i.e. either visually estimating comb surfaces covered by brood and adult workers or analysing images of combs taken in the field and/or laboratory; Cornelissen et al. 2009; Wilson and Johnson 2011; Jeker et al. 2012; Avni et al. 2015; Hoeferlin and Hoeferlin 2015; Colin et al.

2018; Wang 2019). Current image-based techniques for brood area and store size estimation are more invasive than the Liebefeld Method because they require removal of the adult workers from the combs. In addition, colony strength estimation methods that rely on technology can suffer from practical limitations (e.g. beekeeping gloves not compatible with sensitive electronic devices, screens not conducive to reading in the field due to strong sunlight, and long transport distances between colony sites and laboratory facilities). A recent study concluded that the Liebefeld Method produced estimates of colony strength faster than an image analysis program did and that the method was reliable, reproducible and introduced no user bias, making it optimally suited as a field method (Bargen et al. 2019).

A quarter of a century ago, the Liebefeld Method established the fundamentals for efficiently and accurately quantifying colony strength and for monitoring colony development over time. New technologies cannot at present compete with the human eye to measure these parameters. By improving access to the Liebefeld Method, we hope to promote further development and automation of this fundamental tool for beekeepers and honey bee researchers.

CONTRIBUTIONS

BD wrote the first draft, BD, VD, AI, JDC participated in revisions.All authors read and approved the final manuscript.

OPEN ACCESS

Note scientifique sur la «Méthode Liebefeld» pour l'estimation de la force des colonies d'abeilles mellifères: historique, application et traduction

Apis mellifera / **développement des colonies / force des colonies / estimation des colonies / santé des abeilles.**

Eine wissenschaftliche Notiz betreffend der «Liebefelder Methode» zum Schätzen der Volksstärke von Honigbienen: Geschichte, Anwendung und Übersetzung

Apis mellifera / **Volksentwicklung / Volksstärke / Volksabschätzung / Honigbienengesundheit.**

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Beekeeper	Apiary		Date / Time	
Hive typ	Colony		Weather	
Observations			Flight activity	

Cell width (mm) worker: **5.4** drone: **6.5**   Honey per dm^2 (g) **150**

Start	Brood chamber							Super							Observations
L R	Adult workers	Cell numbers					kg	Adult workers	Cell numbers					kg	
Frame		closed brood	open brood	drone brood	Pollen	Honey	Honey		closed brood	open brood	drone brood	Pollen	Honey	Honey	
1a															
1b															
2a															
2b															
3a															
3b															
4a															
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