Selection Index

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Towards a Selection Index for Western Canadian Bee Breeders

Results from a 2007 Beekeeper Survey

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The Case for Selection on Discreet Traits

At the fore of all bee breeding forethoughts is the identification of traits that need to be improved. Frequently these traits are identified by an intuitive (and sometimes panicked) aggregative rating: "I am breeding in two weeks. I will go through my colonies and pick the ten best looking ones for breeders". While this common selection scheme has worked well for beekeepers it can result in relatively slow improvement.

Selection on defined traits is more efficient. A good example of this comes from a 1990s study by Drs. John Harbo and Jeff Harris at the U.S.D.A. laboratory in Baton Rouge, LA. They determined the underlying additive genetic variation behind a number of varroa-resistant traits in a breeding population. Three non-specific traits (mites per 1,000 adult bees, final mite population and the number of mites in 100 brood cells) were only marginally heritable and would, consequently, result in slow improvement in varroa resistance. By contrast, more specific traits (hygienic behaviour, varroa sensitive hygiene (VSH) and the proportion of mites in brood cells) were highly heritable, resulting in rapid gains.

The incorporation of defined traits into a breeding program, nonetheless, throws up considerable obstacles. Perhaps the biggest obstacle is that selection on traits increases costs. While some traits can be assessed during the course of a routine inspection of the brood nest, others demand additional visits to the bee yard and large investments of labour. In a perfect world you would only assess a trait if the anticipated increase in colony productivity from selection exceeded the cost of making the measurements. In practical terms such a calculation is impossible, so in the end, only traits of high value are singled out for selection. Less valuable traits are either assessed crudely or are selected for indirectly in the general catch-all category of: "how does the colony look in general".

Another obstacle is how to weight different traits during selection. Some queen breeders, for example, will select a colony with a slightly higher than average propensity to sting, by virtue of the fact that it produces twice the average amount of honey. The production of honey, consequently, is weighted higher than the aggressiveness of a stock. The degree of weighting, however, is often determined arbitrarily and not in accordance to the actual economic value of the trait.

A final obstacle is that our understanding of various colony traits remains poorly understood. We are not only uncertain of the extent to which different traits have an underlying genetic basis, but also the degree to which these traits are linked. For example, the following three traits are often considered as discreet, but as every beekeeper knows intuitively, they are related: colonies that overwinter well (trait 1), tend to build-up quicker in the spring (trait 2) and, in turn, tend to make more honey (trait 3). Asserting that trait 3 is four times more important than traits 1 and 2 may be missing the point that selection must proceed equally on all three to gain the benefit of any one. The treatment of these traits as discreet is a symptom of our inadequate understanding of the quantitative genetics of bees. This is a fact of life for bee breeders and is not likely to change soon.

A Modified Selection Index

Two researchers at the University of Guelph in the 1990s (Dennis van Englesdorp and Dr. Gard Otis) proposed a solution to our lack of knowledge: sidestep the issue of trait heritability and weight traits exclusively according to their value to beekeepers. Although this approach had been previously proposed in a theoretical form and although many bee breeding programs had used score card systems to weight multiple traits in selection decisions, none previously had established the economic values in a concrete and systematic way.

The University of Guelph researchers determined the economic values of various beekeeping traits by surveying all registered beekeepers in Ontario in 1994 with more than 100 colonies (van Englesdorp and Otis 2000). The survey asked these beekeepers to allocate 100 points among a list of traits and to indicate the relative value to their business (Table 1).

Ontario beekeepers placed the highest value on traits relating to honey production, disease resistance, overwintering ability, and spring build-up: together these traits constituted over 80% of the total value. These values were then used to design a weighted selection index that enabled them to evaluate different stocks for their ability to meet the needs of Ontario beekeepers.

Western Canadian Survey

We were interested in deriving a similar selection index for beekeepers in Western Canada. We did this by surveying beekeepers in British Columbia, Alberta, Saskatchewan and Manitoba using the Ontario survey. We solicited surveys through each Provincial Apiculturalist, in each provincial beekeeping magazine (December 2007 or January 2008 issues), at the British Columbia Honey Producers Association meeting in Dawson Creek (20 October 2007), regional beekeeper meetings in British Columbia (Kootenay, Surrey, Langley and South Okanagan) and by posting a link to the survey on the BC Honey producers website.

We received 77 completed surveys between October 2007 and March 2008, the majority from BC (Table 2). This constitutes a response from only a small fraction of the 4,500 beekeepers in Western Canada and, as such, the results should be considered preliminary. The response came from beekeepers that operated higher than average numbers of colonies (Table 2). Alberta beekeepers in our study purchased five times the number of queens than the 2006 provincial average (Alberta 2006 Beekeeper's Survey, Alberta Agriculture and Food).

The majority of respondents from BC (66%) were provided with an earlier version of the survey that: a) did not request information on the number of colonies operated by the beekeeper and b) did not differentiate between the number of queens produced within the operation and the number purchased externally (for all other surveys 'No. Queens' is the number of queens purchased from external sources).

There are notable changes from the survey results from the primacy of honey production has been reduced in favour of an increased emphasis on varroa resistance. This change may reflect regional differences in the importance of varroa, but may also be in response to the nationwide spread of acaricide resistance since 1994. The importance of rapid spring brood build up, outside of beekeepers with < 100 colonies, was also higher in the current study compared to the results in Ontario. In BC, there is also a notable increase in the importance of nosema resistance, which was not evident among respondents from the Prairie Provinces.

Queen breeders who sell their queens to regions different from their own should take note of these findings. Bee breeders in B.C. who sell queens to Prairie Provinces should be aware that their customers have a disproportionately higher expectation for stock improvement in honey production. These bee breeders might consider weighting honey production higher than they themselves would expect.

Selection Index – A Working Example

A selection index is a comprehensive way to simultaneously assess potential breeding colonies across a number of traits by incorporating their relative economic importance, heritability and genetic relationships. In the words of one of its earliest pioneers, Dr. Jay Lush, each trait is weighted in a way to maximize efficiency:
With our selection we want the maximum returns from the effort we spend. If a character (trait) is only slightly hereditary, we get only a little return for expending some selection on it. If another is highly hereditary, we get much return from selecting for it. Consequently, it is wise to put more emphasis on the highly hereditary characters but that, of course, needs to be tempered by considering the economic worth of the gains we do make. For instance, it is worth more effort to get half of something worth 30 cents than one-tenth of something worth $1! If all the genetic and phenotypic correlations were zero, the proper weight to be placed on each character would be proportional to the product of its heritability and its economic importance.

Table 1. Comparative value of colony traits and beekeeping related income from small (< 100 colonies) and large (>100 colonies) Western Canadian beekeepers. The same data is also presented by region. Data is contrasted with results of an identical survey from Ontario in 1994 of all beekeepers with > 100 colonies (Englesdorp and Otis 2000).

	% response					
	Ontario (1994)	<100 colonies	>100 colonies	BC Total	Prairies Total	Total
No. Colonies per Beekeeper[a]	na	15 ± 4	1360 ± 583	69 ± 21	1642 ± 725	724 ± 324
No. Queens Purchased per Beekeeper	na	5 ± 2	368 ± 211	79 ± 27	349 ± 27	133 ± 57
No. Respondents BC	0	15	6	62	0	62
No. Respondents AB	0	0	4	0	4	4
No. Respondents SK	0	0	5	0	5	5
No. Respondents MB	0	2	4	0	6	6
TOTAL	58	17	19	62	15	77
Colony Trait						
Honey Production	34.4 ± 2.4	21.6 ± 4.5	22.2 ± 2.8	20.0 ± 2.1	29.3 ± 4.4	21.9 ± 1.9
Resistance to Tracheal Mites	8.8 ± 0.8	5.2 ± 0.9	4.3 ± 0.9	6.9 ± 1.2	4.5 ± 0.9	6.3 ± 1.0
Resistance to Nosema	3.4 ± 0.4	6.5 ± 0.8	4.2 ± 0.6	9.9 ± 2.4	3.5 ± 0.6	8.7 ± 2.0
Resistance to American foulbrood	6.4 ± 0.9	7.5 ± 0.9	4.8 ± 0.7	8.7 ± 1.4	4.5 ± 0.7	7.8 ± 0.9
Resistance to Chalkbrood	3.0 ± 0.42	3.6 ± 0.8	3.7 ± 0.7	4.6 ± 0.6	3.9 ± 0.8	4.5 ± 0.5
Resistance to Varroa Mite	9.9 ± 1.5	13.0 ± 2.3	12.2 ± 2.0	14.5 ± 1.3	13.2 ± 2.4	14.4 ± 1.1
Overwintering Ability	10.0 ± 0.8	11.6 ± 3.9	16.5 ± 3.8	11.2 ± 1.7	13.7 ± 1.7	11.6 ± 1.4
Spring Brood Build-Up	6.4 ± 0.7	6.3 ± 0.9	9.7 ± 1.5	11.9 ± 2.0	8.6 ± 1.7	11.2 ± 1.6
Fall Termination of Brood Rearing	2.2 ± 0.3	4.4 ± 1.1	4.4 ± 1.1	5.1 ± 1.4	1.9 ± 0.6	4.4 ± 1.1
Ability to Store Winter Food	2.0 ± 0.4	5.4 ± 0.9	3.5 ± 0.9	7.4 ± 1.2	2.8 ± 0.9	6.4 ± 1.0
Tendency to Swarm	4.3 ± 0.5	6.0 ± 0.9	4.1 ± 0.7	8.4 ± 1.7	3.4 ± 0.7	7.4 ± 1.4
Temperament	5.5 ± 0.6	6.4 ± 0.9	7.4 ± 1.0	6.6 ± 0.7	7.2 ± 1.3	6.7 ± 0.6
Stability/Calmness on the Comb	2.5 ± 0.4	4.4 ± 0.7	3.8 ± 0.9	6.1 ± 0.8	2.7 ± 0.8	5.5 ± 0.7
Other	0.5 ± 0.3	0.6 ± 0.6	0.5 ± 0.4	0.4 ± 0.3	0.7 ± 0.5	0.5 ± 0.2
Source of Bee Related Income						
Pollination	6.0 ± 2.4	1.2 ± 0.7	11.4 ± 4.7	14.0 ± 2.4	3.6 ± 3.3	12.2 ± 0.2
Farm gate honey sales	22.7 ± 3.5	52.6 ± 9.9	10.8 ± 5.0	39.9 ± 4.5	17.3 ± 8.5	35.4 ± 4.0
Self packed honey retail	20.1 ± 3.6	17.9 ± 7.3	14.5 ± 5.8	21.0 ± 3.5	18.1 ± 7.9	21.0 ± 3.5
Bulk honey sales	37.0 ± 4.7	0.6 ± 0.6	44.4 ± 9.0	22.0 ± 3.9	52.5 ± 10.3	13.2 ± 3.1
Queen sales	0.8 ± 0.4	1.2 ± 0.9	5.0 ± 2.6	3.9 ± 1.3	1.5 ± 0.8	3.4 ± 1.0
Nuc / colony / package sales	2.7 ± 0.9	8.5 ± 4.1	9.6 ± 3.1	9.0 ± 1.8	3.9 ± 2.1	8.2 ± 1.5
Other bee products (eg. wax)	4.1 ± 0.6	4.2 ± 1.4	3.2 ± 0.7	3.9 ± 0.7	3.7 ± 0.6	3.7 ± 0.6
Processed bee products	0.9 ± 0.6	2.4 ± 1.1	0.9 ± 0.7	5.0 ± 2.1	2.5 ± 0.6	4.1 ± 0.7
Other	4.4 ± 2.0	12.1 ± 7.5	0.1 ± 0.1	3.4 ± 2.2	0.4 ± 0.3	2.8 ± 1.7

a – A large number of beekeepers from BC (n=44) did not indicate the number of colonies they operated.

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Figure 1. The weight of honey consumed by colonies over the winter is a trait that is being considered by the BC Bee Breeders' Association Queen Testing Project. This Project's objective is to develop varroa-resistant stock adapted to local conditions in BC. The Project is developing a selection index to better select breeders across multiple traits.

The mechanics of weighting within selection indices is somewhat complicated, even when considering the more simplified case without heritability. To help make this easier to understand we actual survey results. This is only an example! It is important when devising your own index to incorporate your experience with a stock and your understanding of the end-users of the stock into the weightings. At our current poor state of understanding of the quantitative genetics of honey bee populations there is no substitute to an accumulated experience of working with a stock. The BC Bee Breeders Queen Assessment Project (Figure 1), for example, will be using the survey results only as a guide. Its final selection index will invariably be tempered by experience and discussions with other queen breeders. For the purpose of this example we will work with the values in the last column of Table 1, titled "Total". Of course, if you are from a specific region you should use the values from a more appropriate column.

Looking through Table 1 we noticed that four traits are somewhat unimportant in Western Canada: fall termination of brood rearing, ability to store winter food, tendency to swarm and stability/ calmness on the comb. In the interest of minimizing the cost of assessing breeders we dropped these traits from our example selection index. It is quite possible that some of these traits are linked to other more valued traits and by dropping them we objectively undermine our stock improvement on other traits. We are dropping them here merely to illustrate the obvious: not all traits need to be considered in your selection index.

Hygienic behaviour is a trait that results in resistance to a number of diseases, including American foulbrood, chalkbrood and varroa mites. To fit the value ascribed to each specific resistance to hygienic behaviour we used van Englesdorp and Otis' strategy of summing the weights assigned by beekeepers for chalkbrood, American foulbrood, and half (arbitrarily determined) the value for varroa mites. Clearly there are other ways to allocate the value of resistance among other traits, but for the purpose of our example we only considered hygienic behaviour.

This leaves us with a seven-trait selection index. These traits are listed across the first row of Table 3.

Table 2. The number of beekeepers surveyed, the number of queens they used within their operationa and the number of colonies per beekeeper by region. Figures are compared to the provincial average for colonies per beekeeper.

Province	No. Beekeepers	No. Queensa	± SE	No. Colonies per Beekeeper	± SE	Ave. Colonies per Beekeeperb
BC	61	79.3	27.0	69.0	21.4	24
AB	4	1109.8	968.2	3530.5	2671.9	347
SK	5	30.4	29.9	1240	214.1	94
MB	6	109.2	81.9	720	350.4	136

a –For a portion of the beekeepers in BC this category includes the number of queens produced and sold. For all other provinces the category only includes the number of queens purchased for the operation.

b –Provincial average number of colonies per beekeeper from 2006 (Canadian Association of Professional Apiculturalists, Annual Report, 2007).

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Table 3. Calculation of z-scores and selection index score for three hypothetical colonies located within the same apiary using the results from the Total column in Table 1. Colony 3 had the highest selection index score and would be selected as the best breeding colony in the apiary.

Colony Data							
Colony	Honey Production (lbs)	Tracheal Mite (%)	Hygienic Behaviour (%)	Nosema (million spores/bee)	Overwinter (Score: 1-5)	Spring Brood Build-Up (Score: 1-5)	Tempera-ment (Score: 1-5)
1	100	5	80	4	3	1	1
2	120	0	85	1	3	3	1
3	300	10	70	0.5	4	4	3
Average	173	5	78	1.8	3.3	2.7	1.7
SD	110	5	8	1.9	0.6	1.5	1.2
Z-Scores = ((Colony Measurement – Apiary Average) / Apiary Standard Deviation (SD))							
1	(100-173)/110 = -0.7	(5-5)/5 = 0	(80-78)/8 = 0.3	(4-1.8)/1.9 = 1.2	(3-3.3)/0.6 = -0.5	(1-2.7)/1.5 = - 1.1	(1-1.7)/1.2 = - 0.6
2	(120-173)/110 = -0.5	(0-5)/5 = -1	(85-78)/8 = 0.9	(1-1.8)/1.9 = -0.4	(3-3.3)/0.6 = -0.5	(3-2.7)/1.5 = 0.2	(1-1.7)/1.2 = - 0.6
3	(300-173)/110 = 1.2	(10-5)/5 = 1	(70-78)/8 = -1	(0.5-1.8)/1.9 = -0.7	(4-3.3)/0.6 = 1.2	(4-2.7)/1.5 = 0.9	(3-1.7)/1.2 = 1.1
Index Sub-Values							
Value	× 21.9	× -6.3	=(7.8+4.5+(14.4/2)) × 19.5	× -8.7	× 11.6	× 11.2	× 6.7
1	-15.3	0.0	5.9	-10.4	-5.6	-12.3	-4.0
2	-11.0	6.3	17.6	3.5	-5.6	2.2	-4.0
3	26.3	- 6.3	-19.5	6.1	13.9	10.1	7.4
Selection Index Results Worst = Colony 1 = -41.7 | Medium = Colony 2 = 9.0 | **BEST = Colony 3 = 38.0**							

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In the example in Table 3 we have an apiary consisting of three potential breeding colonies and we want to choose the best one. Of course, this is a contrived example. A real selection program would look at a lot more than three colonies and the final number of breeders would be more than one colony. We are making an extreme simplification.

Notice that we measure the traits in a number of different units. Honey production is in pounds, tracheal mites in the percentage of adults in a sample of 30 that have at least one tracheal mite, hygienic behaviour in the percentage of frozen brood removed in 24h, etc. Comparing these different measurements would be like comparing apples to oranges. We need to convert these measurements into a common unit: this unit is called a z-score.

Z-scores are calculated. To calculate them you need three numbers: 1) the actual value you measured for the colony you are calculating the z-score for, 2) the average of the trait across all the colonies in the apiary and 3) the standard deviation (SD) of the trait across all three colonies. To calculate the z-score for honey production for colony #1, for example, you: 1) take the honey yield of colony #1 (100 lbs), 2) you subtract the average honey yield for the three colonies in the apiary (173 lbs) and then 3) divide this result by the apiary honey production SD (110 lbs). The z-score for colony #1 turns out to be -0.7 [= ((100-173)/110)]. This is not a very good score. Colony #3, by contrast, has the best z-score (1.2).

After all the z-scores are calculated they need to be converted to index sub-values. To do this you multiply all the z-scores by the weight of that trait. Let's use honey as the example again. For colony #1 the z-score was -0.7. The weighting, from the survey, was 21.9. Consequently, the index sub-value is -0.7 × 21.9 = -15.33.

Not all the index sub-values are so simple to calculate. You will notice that 24 VOlume 24, #2, MAY 2008 for tracheal mite the weighting is -6.3, the same value as in the survey, but negative. The negative was added, of course, because we want to select colonies with low tracheal mites. If we had left the value as positive we would have ended up tragically selecting colonies with high frequencies of tracheal mites.

Now comes the easy part. To determine the selection index score for each colony you simply add together all the index sub-values for a given colony. When you add these up colony #3 is the best breeder colony as it has the highest overall score, 38.0. The high score means colony # 3 had the best blend of traits for beekeepers in Western Canada.

These calculations are readily conducted using a spreadsheet program, such as Microsoft Excel. If you need help getting set up feel free to contact Andony.

Towards a Selection Index for Western Canadian Beekeepers

The selection index outlined in this article is a compromise resulting from a scarcity of information on the quantitative genetics of our breeding populations. This scarcity will not be remedied soon. While important strides forward are being made, most notably in the development of a BLUP-Animal Model for honey bees www.beebreed.eu, it may be sometime before an objective and systematic selection index is available to Western Canadian bee breeders.

The selection index proposed by van Englesdorp and Otis, nonetheless, constitutes an important starting point towards a more systematic method of breeding. Another important component is the practical implementation of this index. The BC Bee Breeders Queen Assessment Project Introduction, for example, provides an invaluable practical testing ground for the idea of a selection index. Such programs are the concrete basis for advancing bee breeding. It is our belief that a continued interaction between theory and practice is the best path towards a more useful and efficient selection program for bee breeding.

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