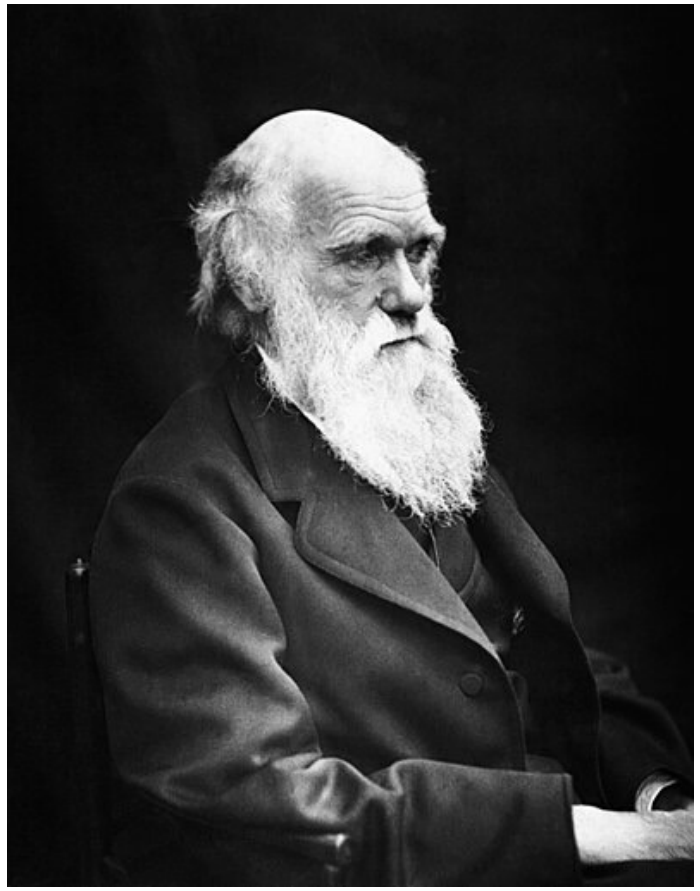
Beekeeping with Darwin

Better-B public event

Séverine Kotrschal

Better-B
FOR RESILIENT BEEKEEPING

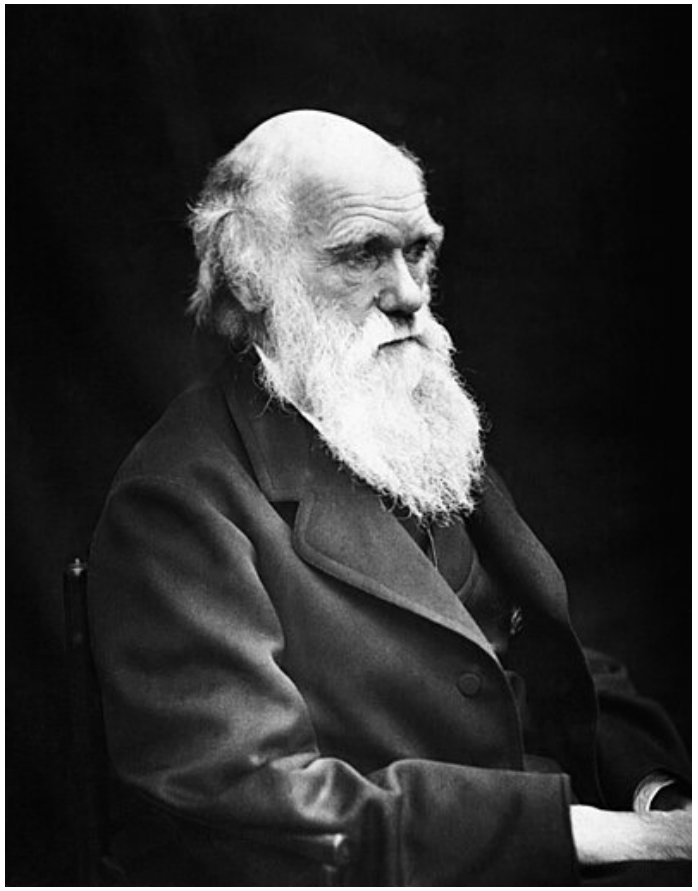
Beekeeping with the help of natural selection

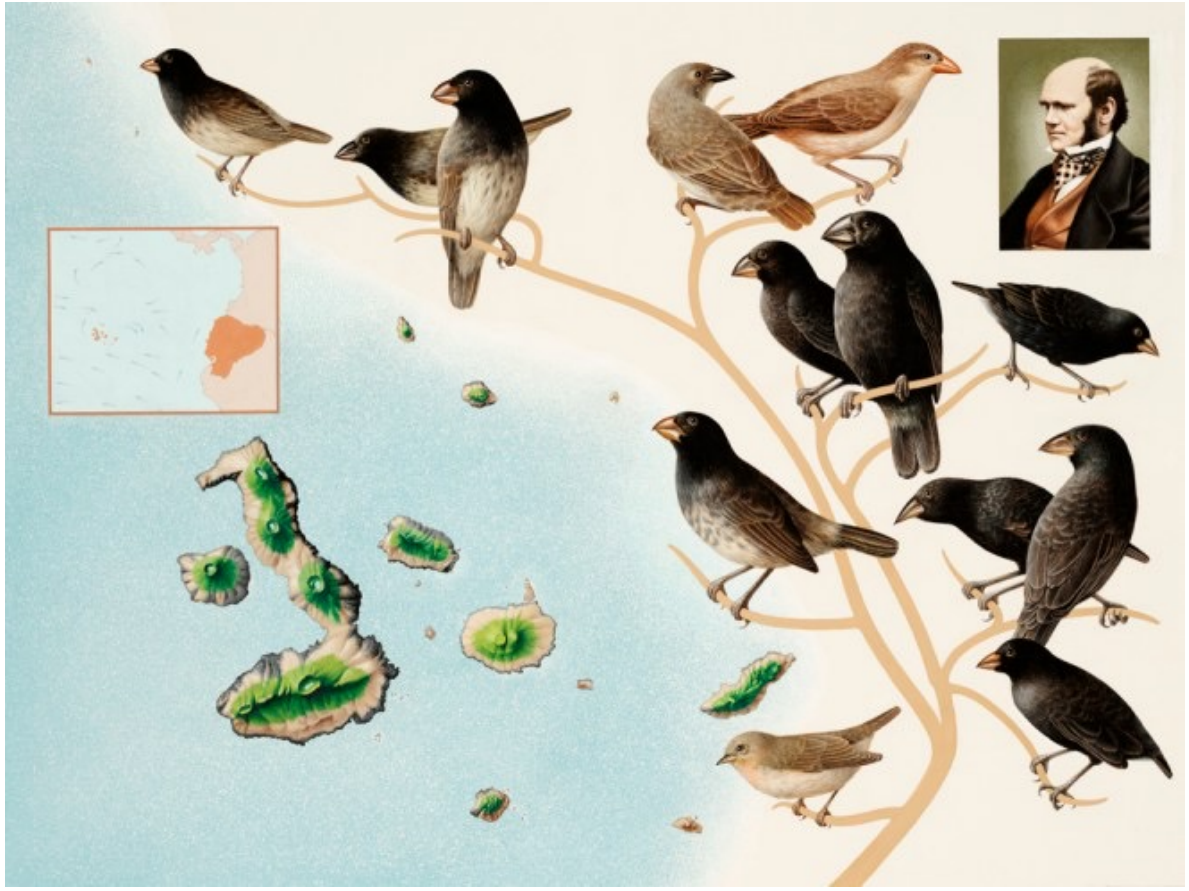


Organisms with traits that are better suited to cope with the challenges of their environment are more likely to survive and reproduce

-> helpful traits are passed on to future generations, allowing the species to adapt to the environment.

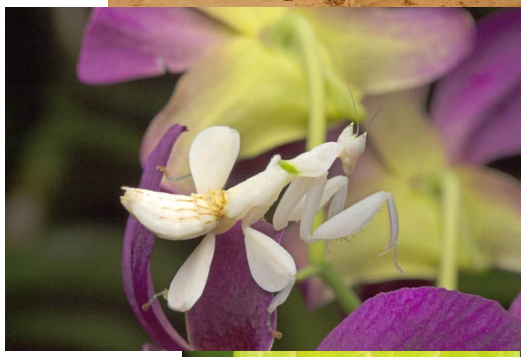
Beekeeping with the help of natural selection



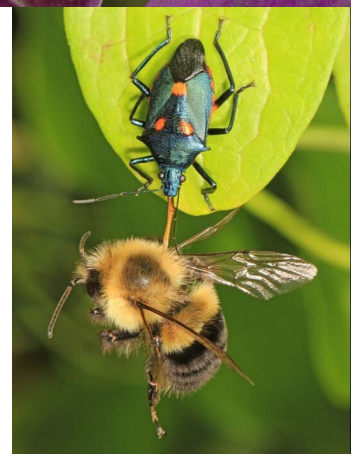


Organism have to adapt to the challenges of the environment in order to survive

- *Food and Water*
- *Climate and Temperature*
- *Habitat and Shelter*
- *Predators and Competition*

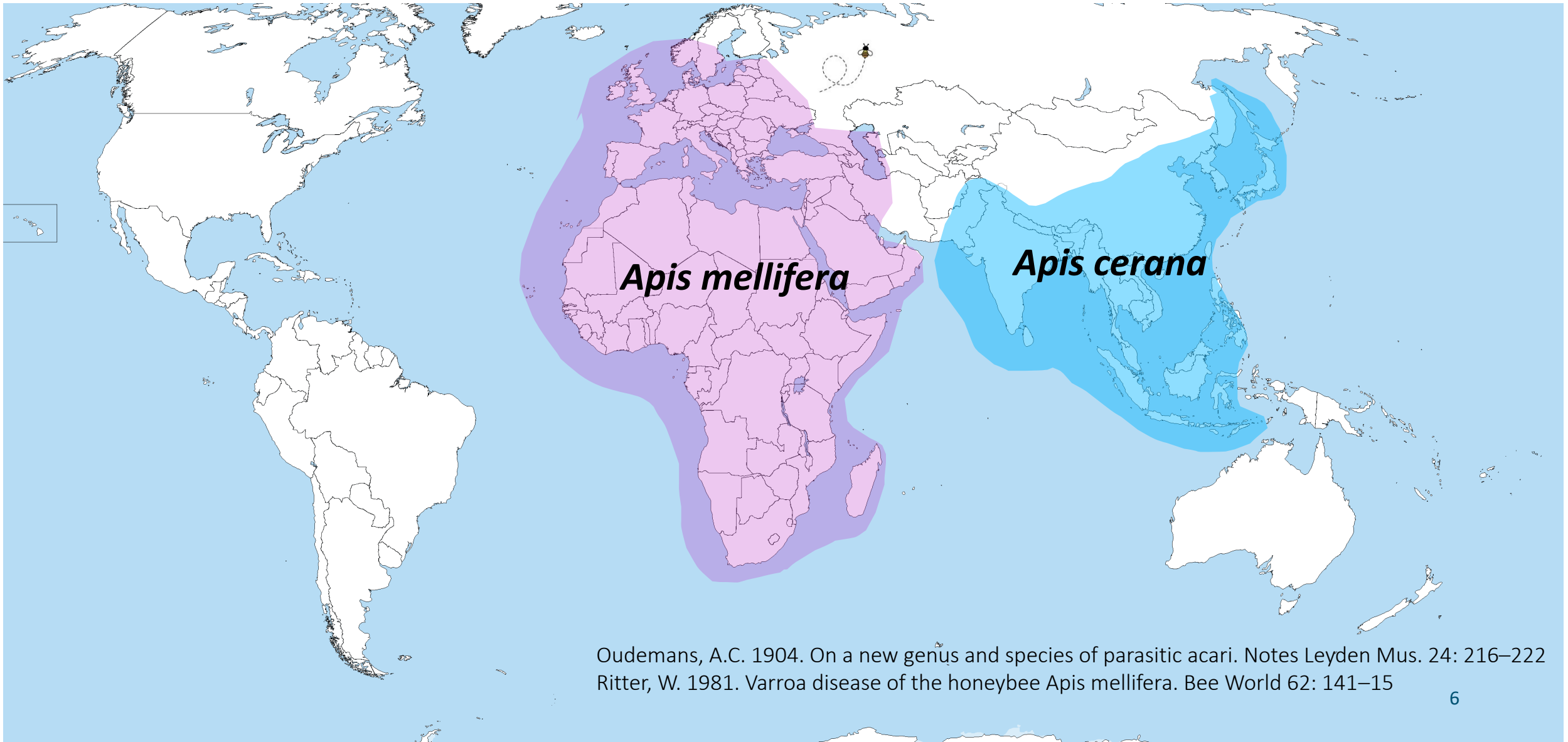


- *Pathogens and Parasites…*



The varroa mite

- First described from *Apis cerana* in Indonesia in 1904
- Ignored until early 1980s when it was found to cause damage to ***Apis mellifera***



Oudemans, A.C. 1904. On a new genus and species of parasitic acari. Notes Leyden Mus. 24: 216–222
Ritter, W. 1981. Varroa disease of the honeybee Apis mellifera. Bee World 62: 141–15

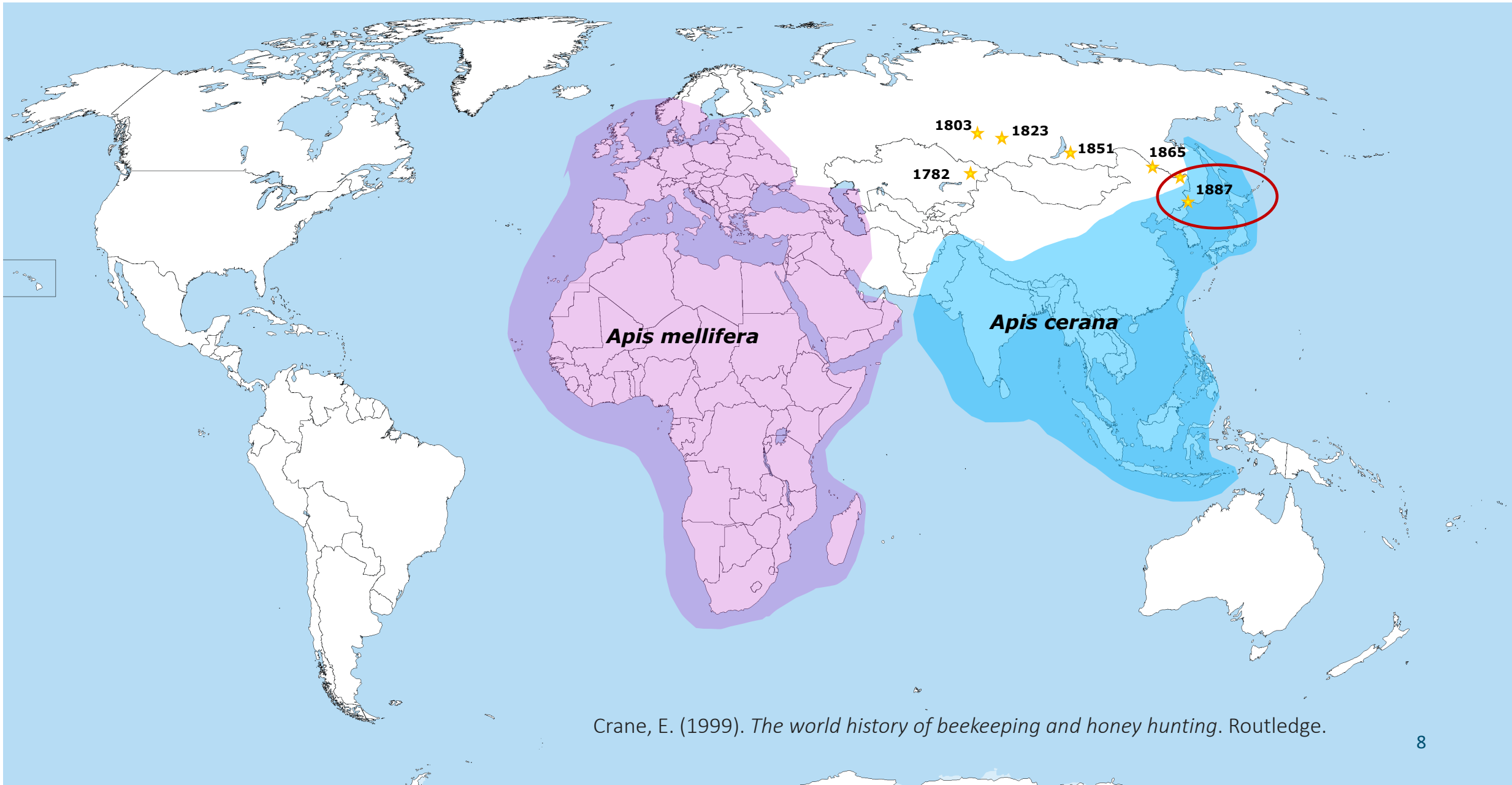
Apis mellifera Beekeeping

The Beekeepers, 1568, Pieter Bruegel the Elder

Bee market, Netherlands 1950’s

Veneendaal bee market, end of 19th century

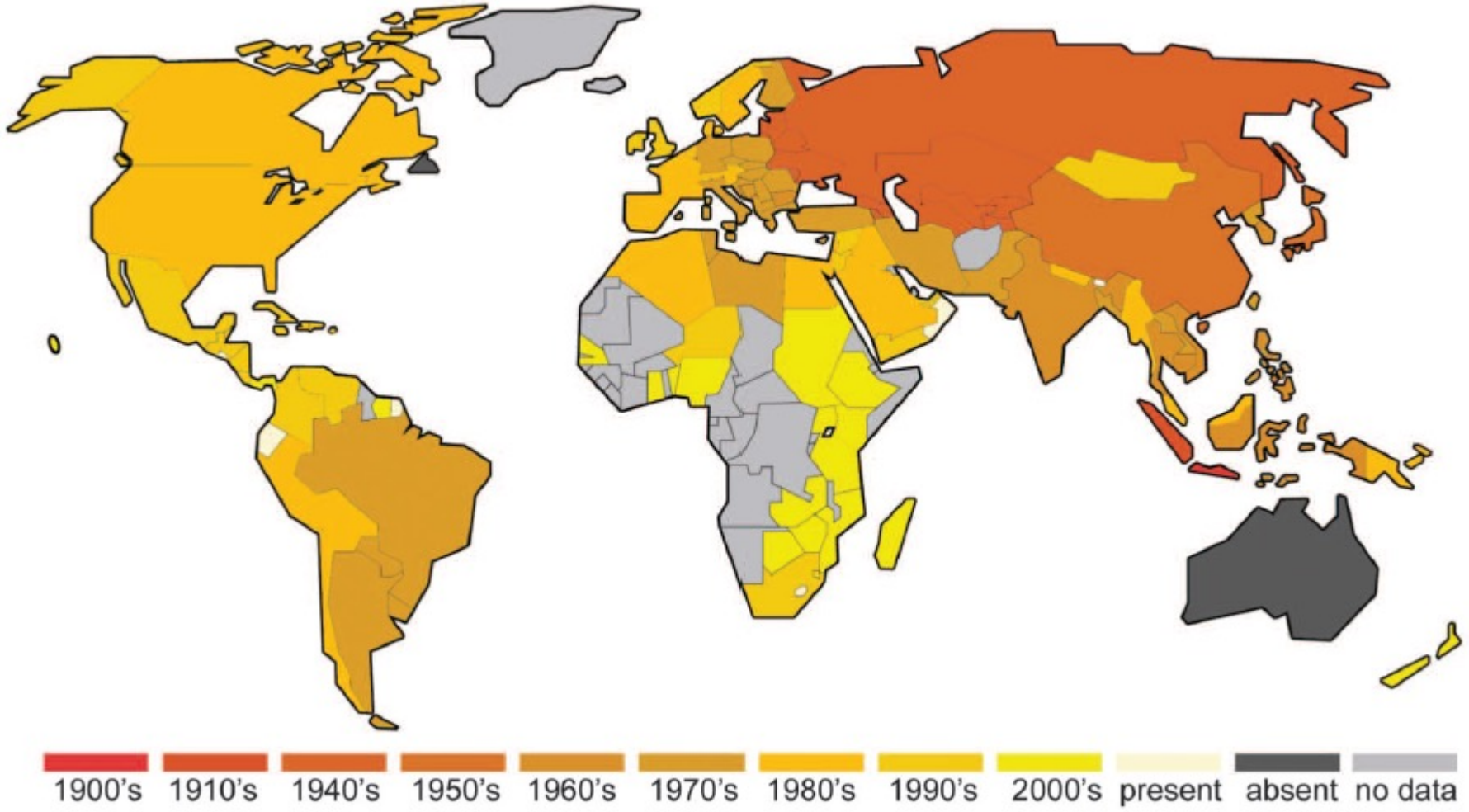
‘Korfhalletje 1890’, Centrum Agrarische Geschiedenis Belgium



Crane, E. (1999). *The world history of beekeeping and honey hunting*. Routledge.

Beekeeping- use of *A.mellifera* worldwide

Worldwide expansion of *Varroa destructor*

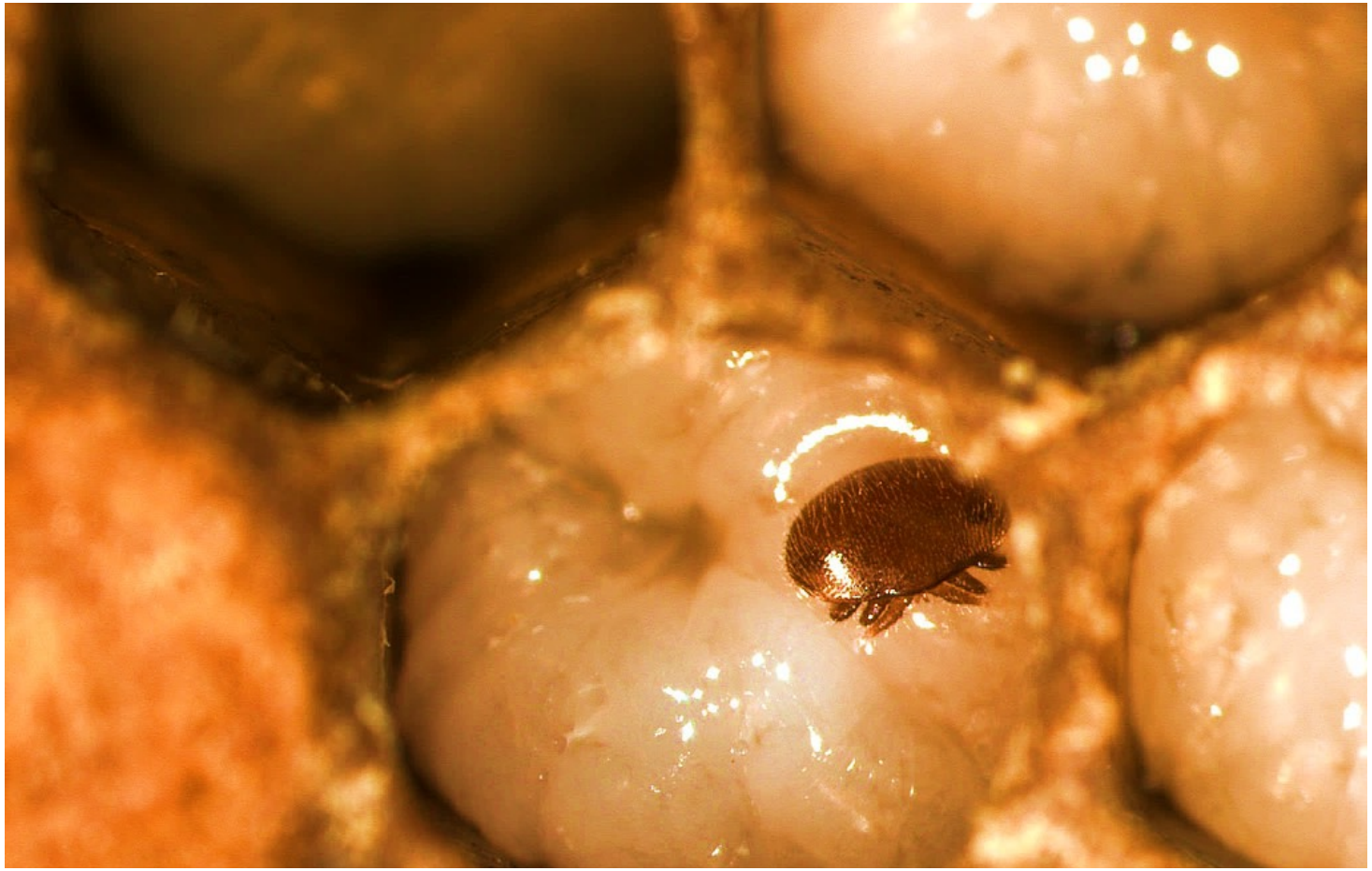


Wilfert, et al., 2016. Science

Varroa: Why does it harm *A.mellifera?*

- Varroa feeds on haemolymph and fat bodies of bees

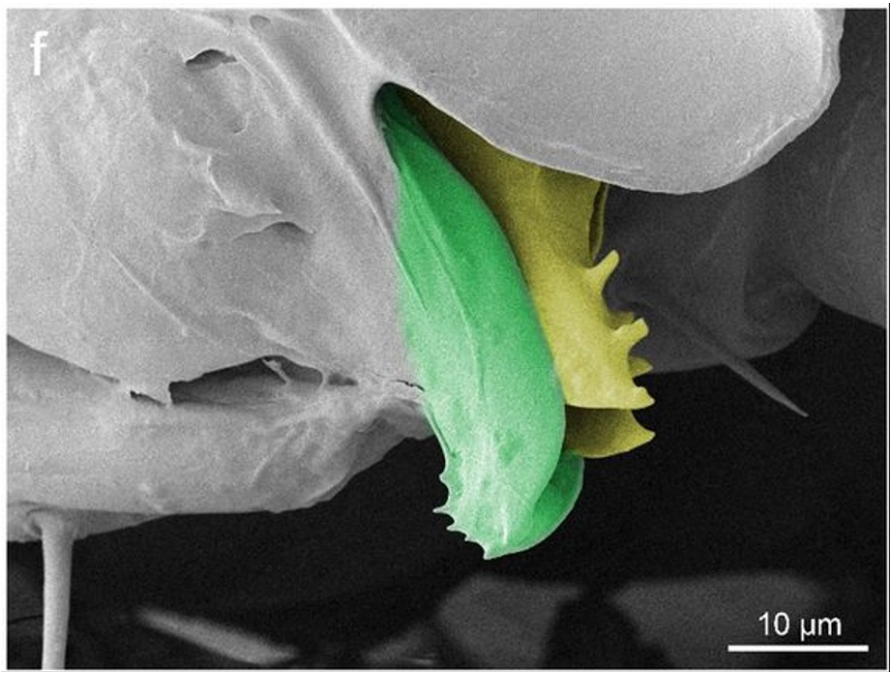
Ramsey *et al.,* 2019

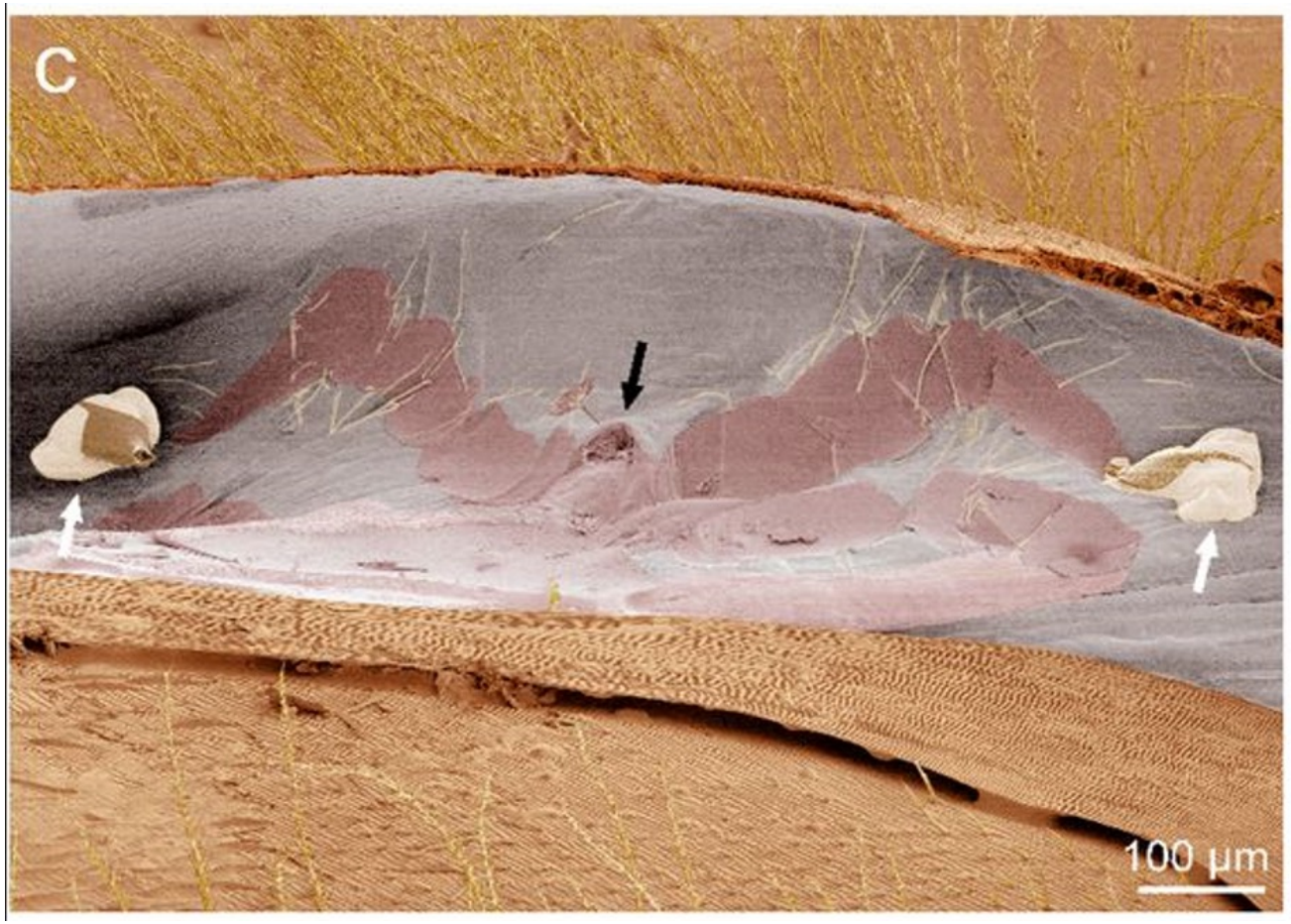


Rosenkranz *et al.*, 2010. *Journal of invertebrate pathology*

Varroa: Why does it harm *A.mellifera?*

- Vectors harmful viruses!

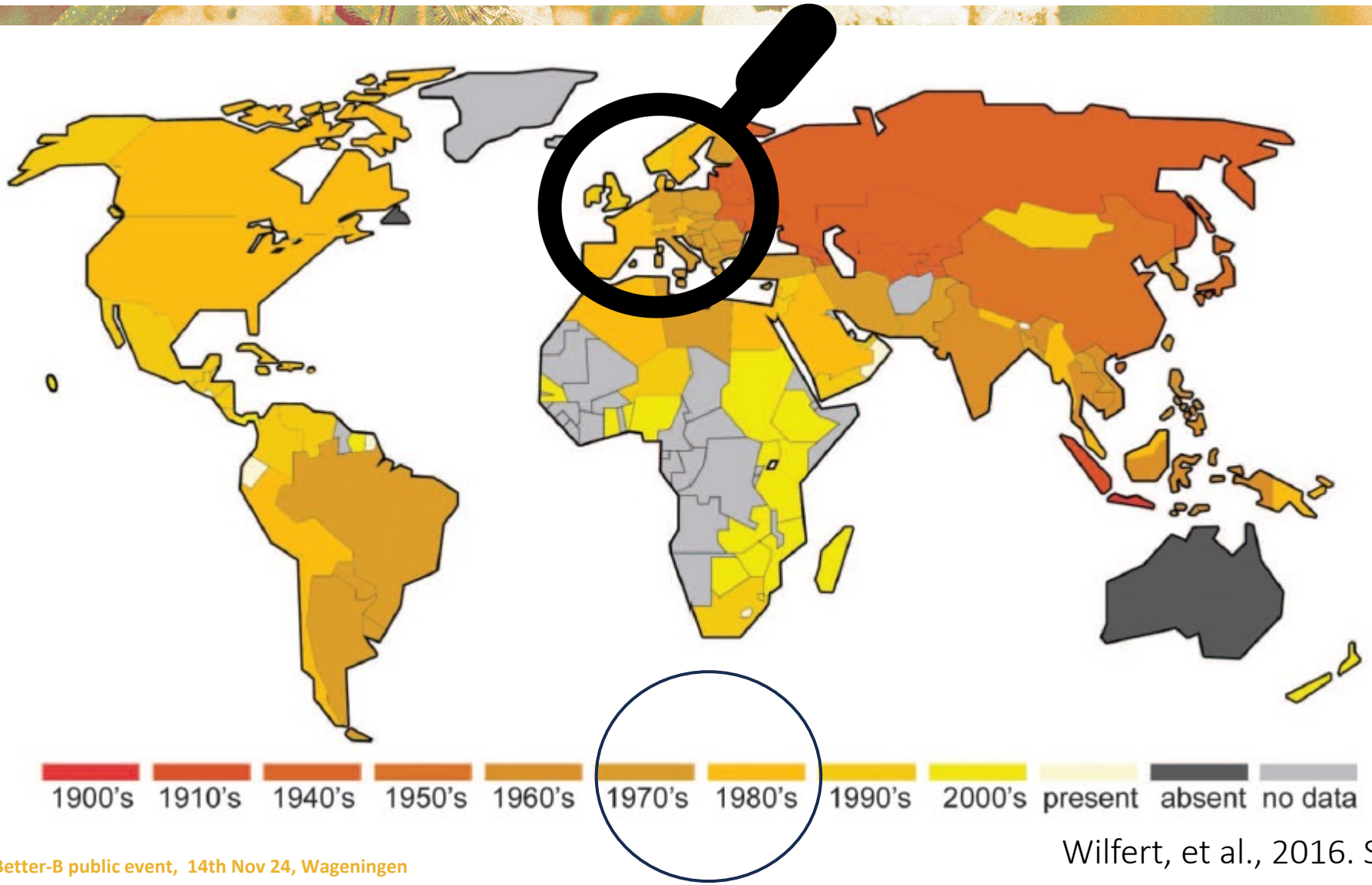




Ramsey *et al.,* 2019

Similar picture all over Europe

Worldwide expansion of *Varroa destructor*



Wilfert, et al., 2016. Science

What makes this difference?

- More than 40 years after the Varroa mite invasion, most honeybees in Europe are not resistant…

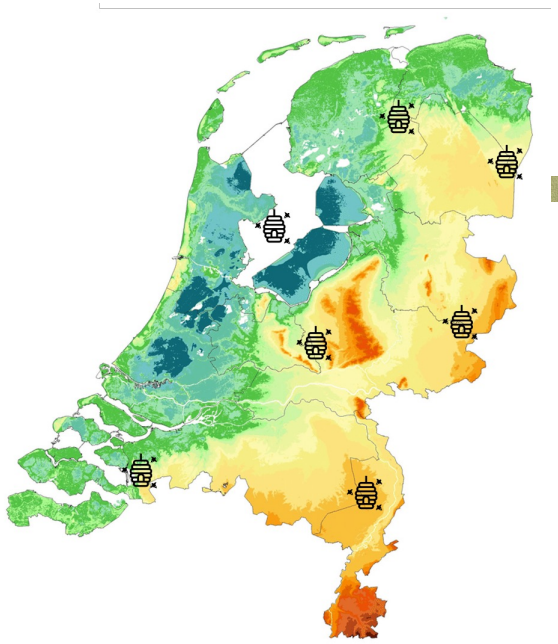
- …while in S. Africa and S. America, honeybees have adapted to Varroa within 5 years of its arrival.

(Allsopp, 2005, Schafaschek et al., 2019)

What makes this difference?

Beekeeping in Europe

- ≈ 80 000 managed honey bee colonies (NL)
- ≈10 800 beekeepers



- ≈ 17 Million hives (Europe)
- ≈ 620 000 beekeepers

European Commission

The long tradition of European beekeeping certainly plays a role.

- **Queen breeding**
  - ↓aggression
  - ↓ swarming behaviour
  - ↑ honey production

- **Varroa treatment**

Natural selection: How does it work

The honeybee has more than 10000 genes

- Variants of a gene -> Allel

Natural selection: How does it work

Low resistance

High resistance

- Some of these alleles are more favorable in the case of varroa infestation
- Not all colonies may have all these alleles

Natural selection: How does it work

Without varroa treatment

Low resistance

High resistance

- Colonies carrying the red, more resilient alleles have a survival advantage

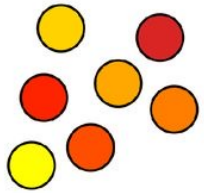
Natural selection: How does it work

Without varroa treatment

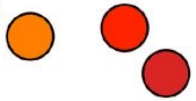
Low resistance

High resistance

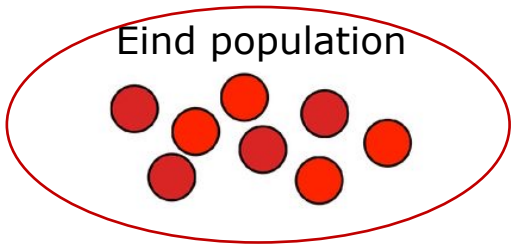
Before selection



After selection



Eind population



Resilient

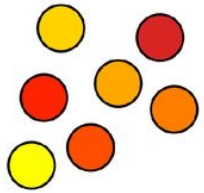
Natural selection: How does it work

Without varroa treatment

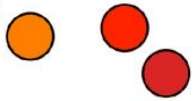
Low resistance

High resistance

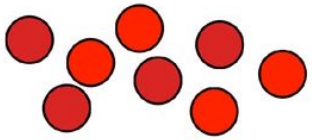
Before selection



After selection

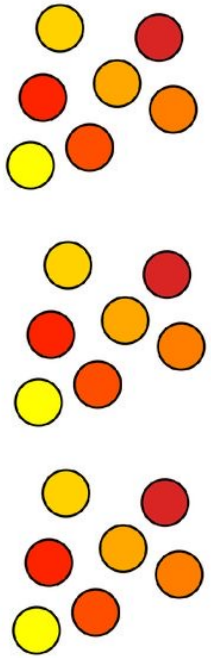


Eind population



Resilient

With varroa treatment



Not resilient

- no more survival benefit

Sweden: Gotland island

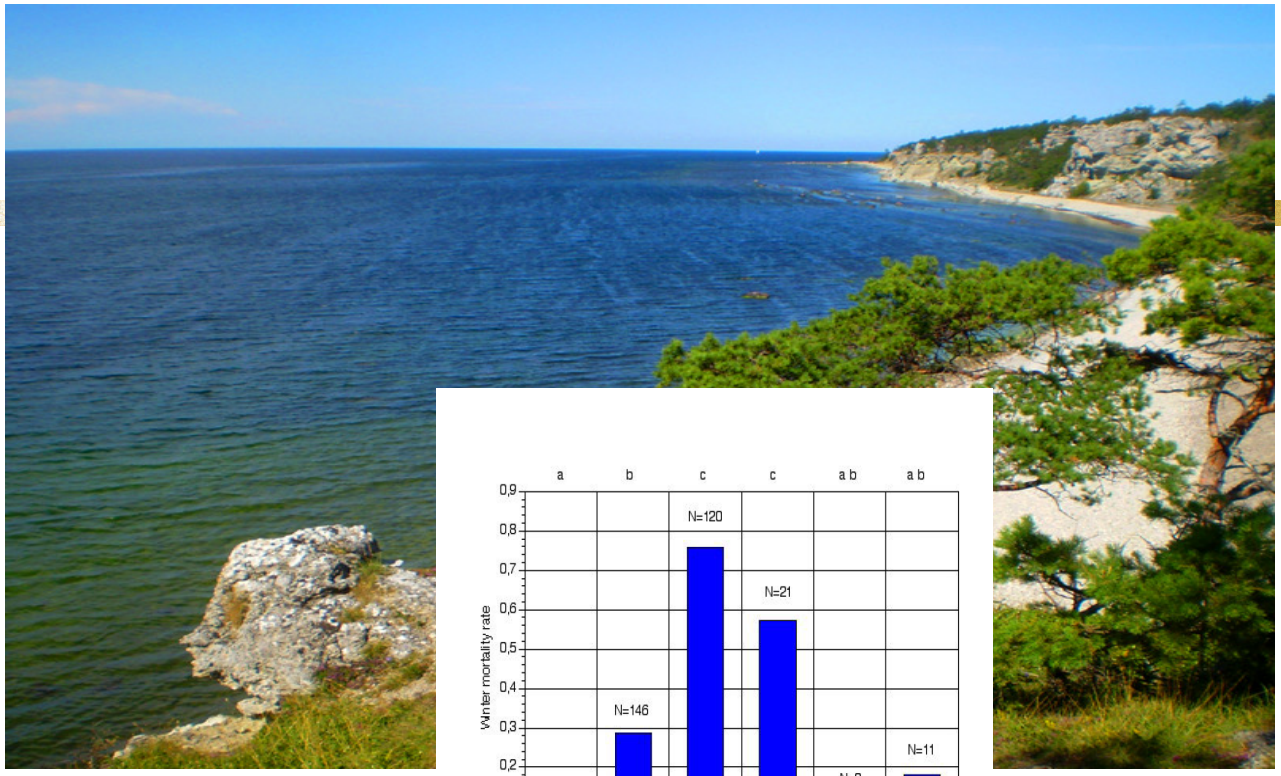


Figure 1. Mortality rate of honey bee colonies over six winters without control of *Varroa destructor*. N = number of colonies in late October each year. Bars with different letters above are significantly different between years ($P < 0.05$, chi-square).

➔'live and let die' experiment 1999

- 150 colonies
- 75% mortality on 3rd year
- 13% and 19% in the following two years

Fries et al.,2006. Survival of mite infested (Varroa destructor) honey bee (Apis mellifera) colonies in a Nordic climate. *Apidologie*, *37*(5), 564-570.

Now in a beekeeping context:

- Reduced mortality

➢ Darwin's Black Box selection

Criteria of selection:

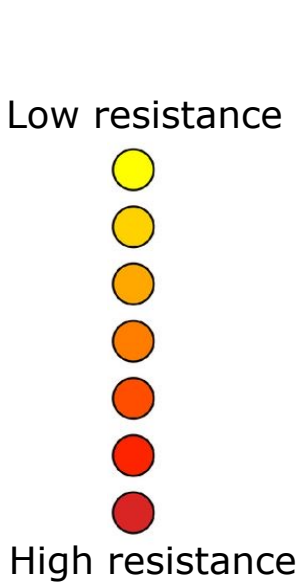
Survival, Growth, Reproduction

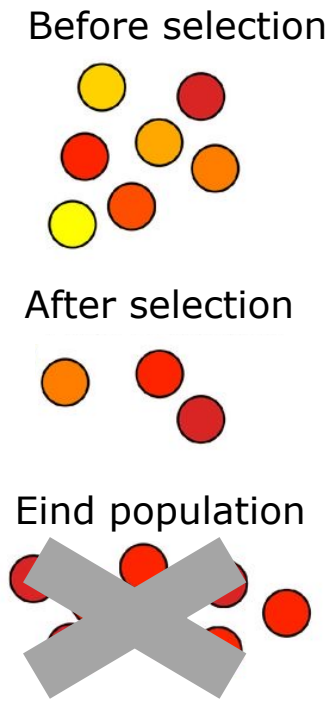
in the absence of Varroa control

- Controlled reproduction
- Isolated mating place (mating island)

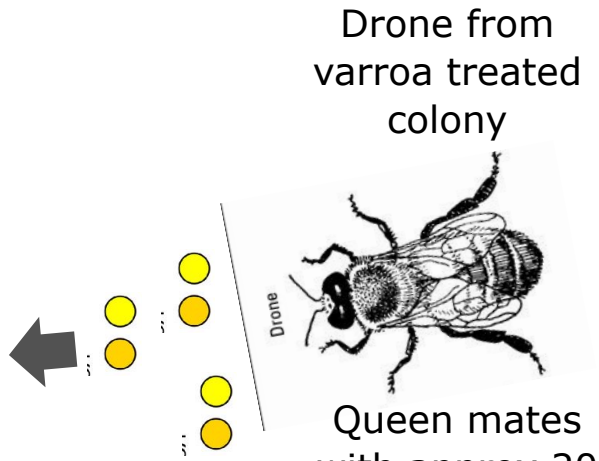
Blacquière *et al*., 2019. Darwinian black box selection for resistance to settled invasive Varroa destructor parasites in honey bees. *Biological invasions*, *21*(8), 2519-2528.

The importance of an isolated mating place (mating island0





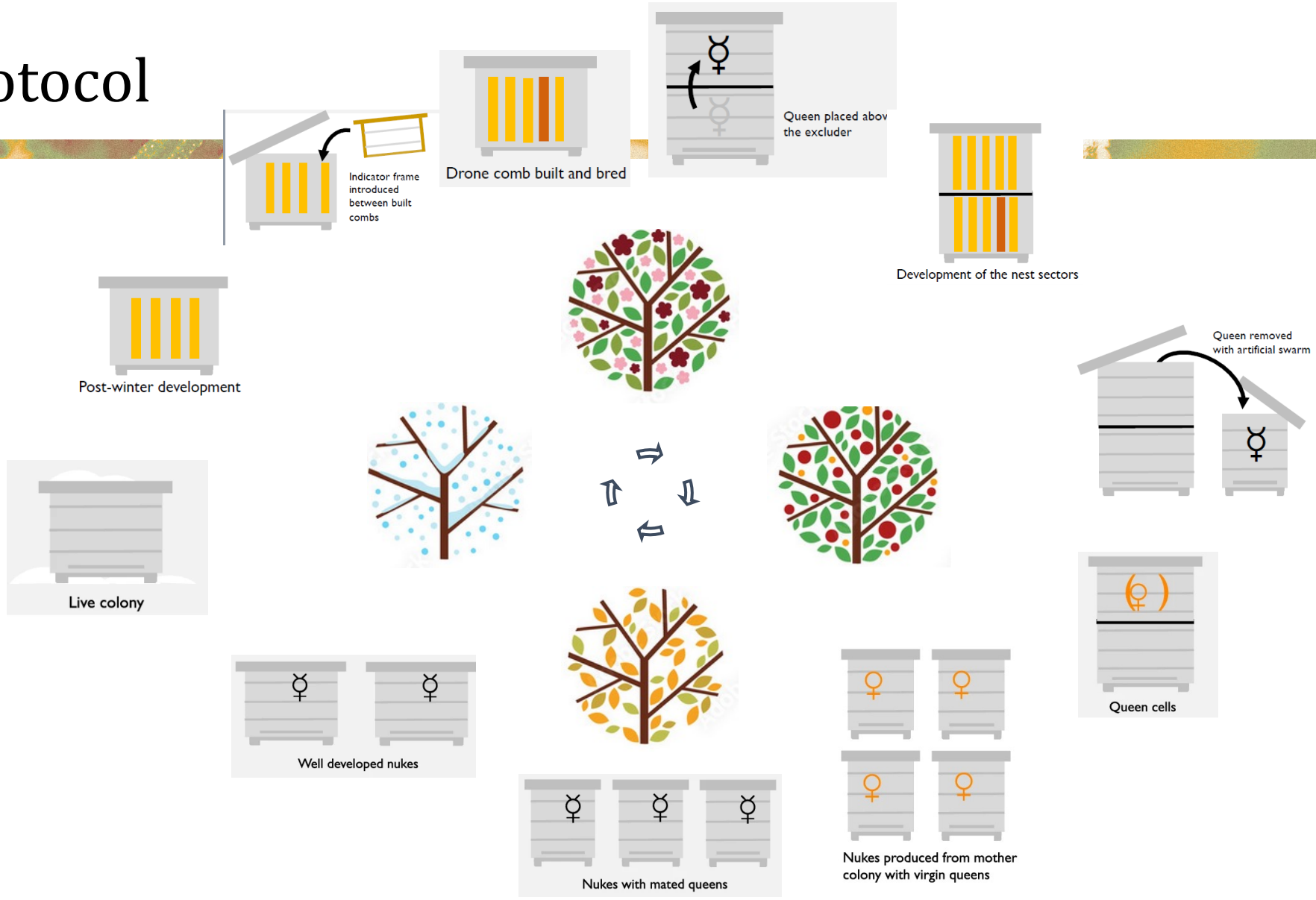
Resistant/tolerant



Island of Tiengemeten (Group 1: 2007-2017)

National Park Hoge Veluwe (Group 2: Lelystad selection, 2008-)

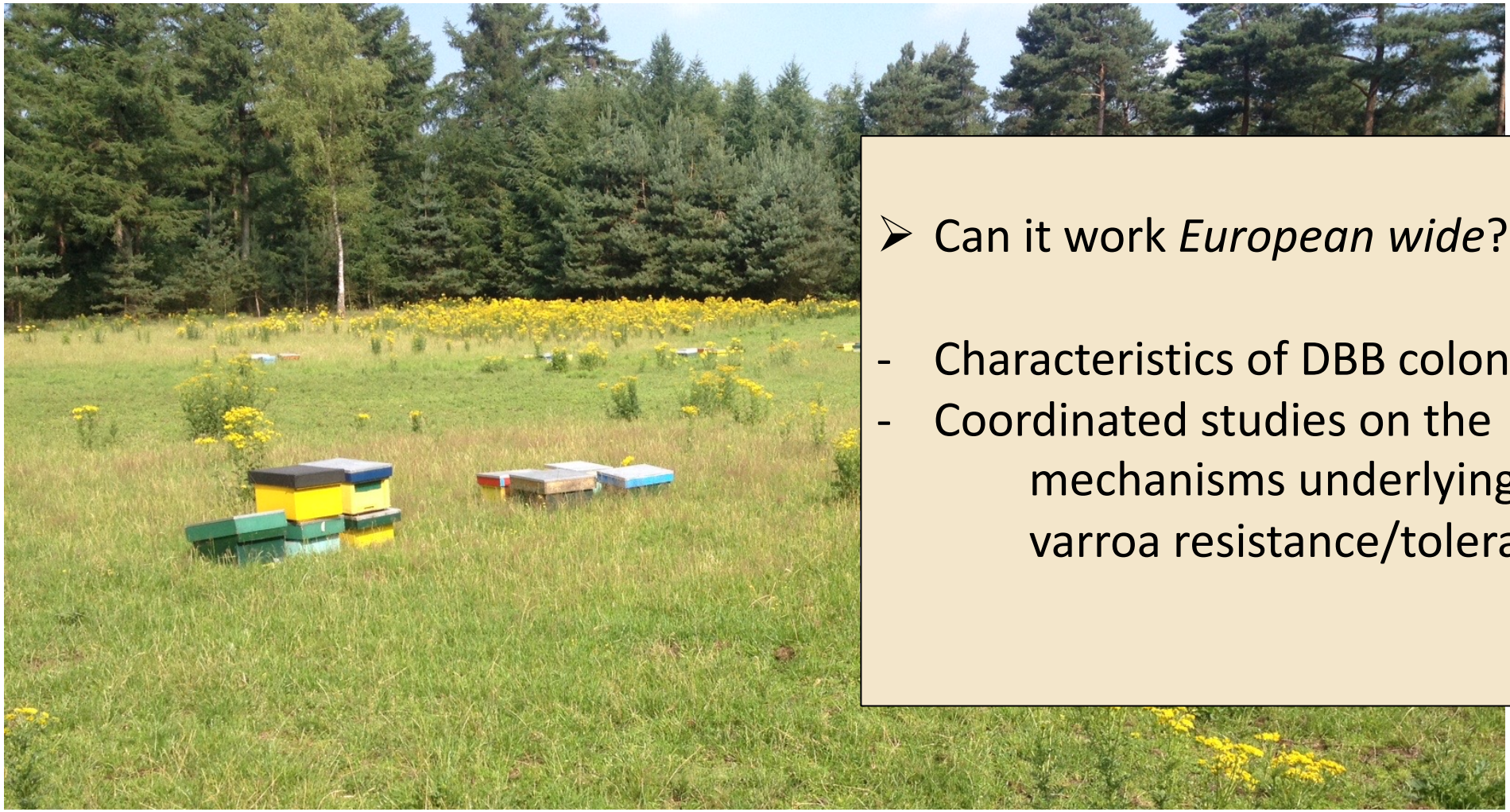
DBB Protocol



Blacquière *et al.*, 2019. *Biological invasions*, *21*(8), 2519-2528.

National Park Hoge Veluwe (Group 2: Lelystad selection, 2008-)

National Park Hoge Veluwe (Group 2: Lelystad selection, 2008-)



- Can it work *European wide*?

- Characteristics of DBB colony?
- Coordinated studies on the mechanisms underlying varroa resistance/tolerance

Darwininan beekeeping within Better-B

- Improving **B**ees r**E**silience **T**o s**T**ressors by r**E**storing ha**R**mony and **B**alance

Darwininan beekeeping within Better-B

Better-B

Resilient beekeeping Consortium

"The key to resilient beekeeping is to harness the power of nature to restore harmony and balance inside the honey bee colony and between the colony and the environment"

Dirk van de Graaf, project coordinator

Pollinator ecology | Resilience to chemicals | Resilience to climate and heat stress | Local adaptation by darwinian selection | Immune resilience | Future of beekeeping

Local adaptation by darwinian selection

Research questions:

What are the characteristics of a Darwinian colony?

What is the impact of mobility of beekeeping sector?

1

2

3

Local adaptation by darwinian selection

Research questions:

What are the characteristics of a Darwinian colony?

What is the impact of mobility of beekeeping sector?

1 Genetic characterization of established D-colonies

2

3

Local adaptation by darwinian selection


Alice Pinto
Matthew Webster

Research questions:

What are the characteristics of a Darwinian colony?

What is the impact of mobility of beekeeping sector?

1 Genetic characterization of established D-colonies

2 Netherlands
Belgium
Norway

3 Test for the genetic signature of local adaptation (climate and varroa)

Local adaptation by darwinian selection

Research questions:

What are the characteristics of a Darwinian colony?

What is the impact of mobility of beekeeping sector?

1 Genetic characterization of established D-colonies

2 Follow-up colonies during process D-selection

3

Applying DBB protocol: European wide

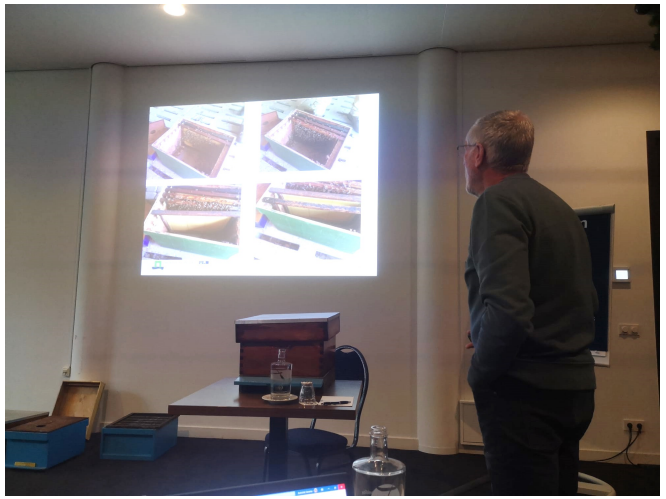
- Belgium –UGENT
- Germany –MLU
- Portugal (Coimbra) –UCOI
- Portugal (Bragança) –IPB
- England –TNTU
- Romania –USAMV
- Spain –IRIAF
- Norway –NB
- The Netherlands –WR

➢ **9 partners / 8 countries**

Better-B Workshop in Wageningen: Nov 2023

- **Discussion on methodological details**
  -details field protocol
- **Special guests:**

- Tjeerd Blacquière (WR in pension)
- Pam van Stratum, Johan Calis, Willem Boot (Inbuzz)



Result of the workshop

Better-B project WP4 Task 4.2:

Untangeling the process of Darwinian selection

PROTOCOL

Worked out during the Better-B workshop in Wageningen
16th & 17th November 2023

Preparations for the start of the experiment in spring 2024:

- Start the experiment with 25 good, genetically diverse colonies (avoid sister queens if possible).
- Label your original colonies according to the labeling system with the unique original_queen_id number (country code_running number, example NL_1, see labelling file uploaded on workshop wepage example page added to this protocol appendix 1). ! Put the label (tape with permanent marker) on the top feeding board inside the colony to protect from weather.
- Make sure you have beekeeping material ready (indicator frames, hive material for 25x4 additional hives for split colonies (brood boxes, frames with wax foundation bottoms, top boards with feeding hole, roof, queen excluders, sugar fondant, straps, honey suppers with built frames, queen cages, apideas (approximately 20).

  NOTE: Make sure that all your experimental colonies and nukes always have a bag of sugar fondant. We want varroa to be the main selection pressure. Also consider using straps to secure colonies at the apiarzy at all time to avoid accidents (wildlife, wind, vandalism etc)

Better-B

WAGENINGEN UNIVERSITY & RESEARCH

Protocol overview

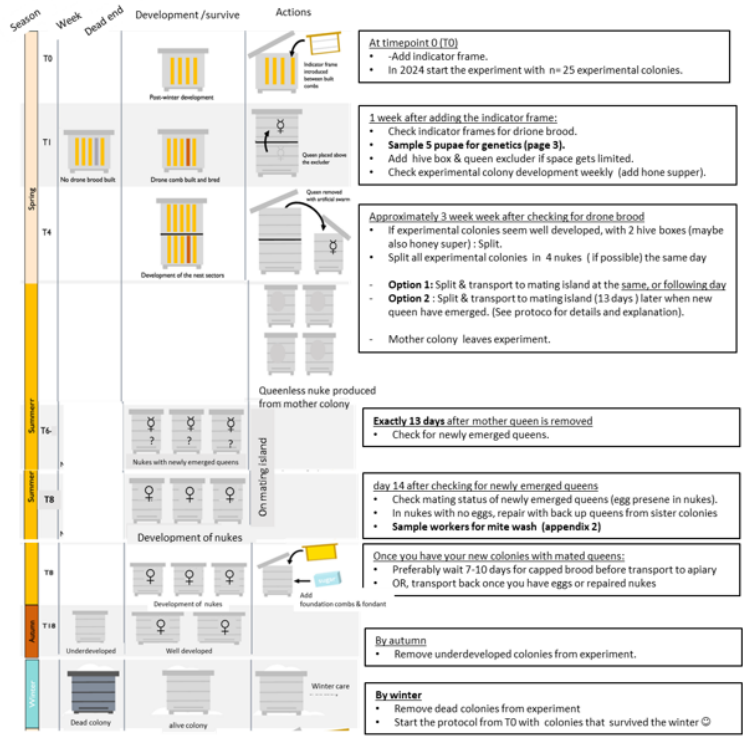


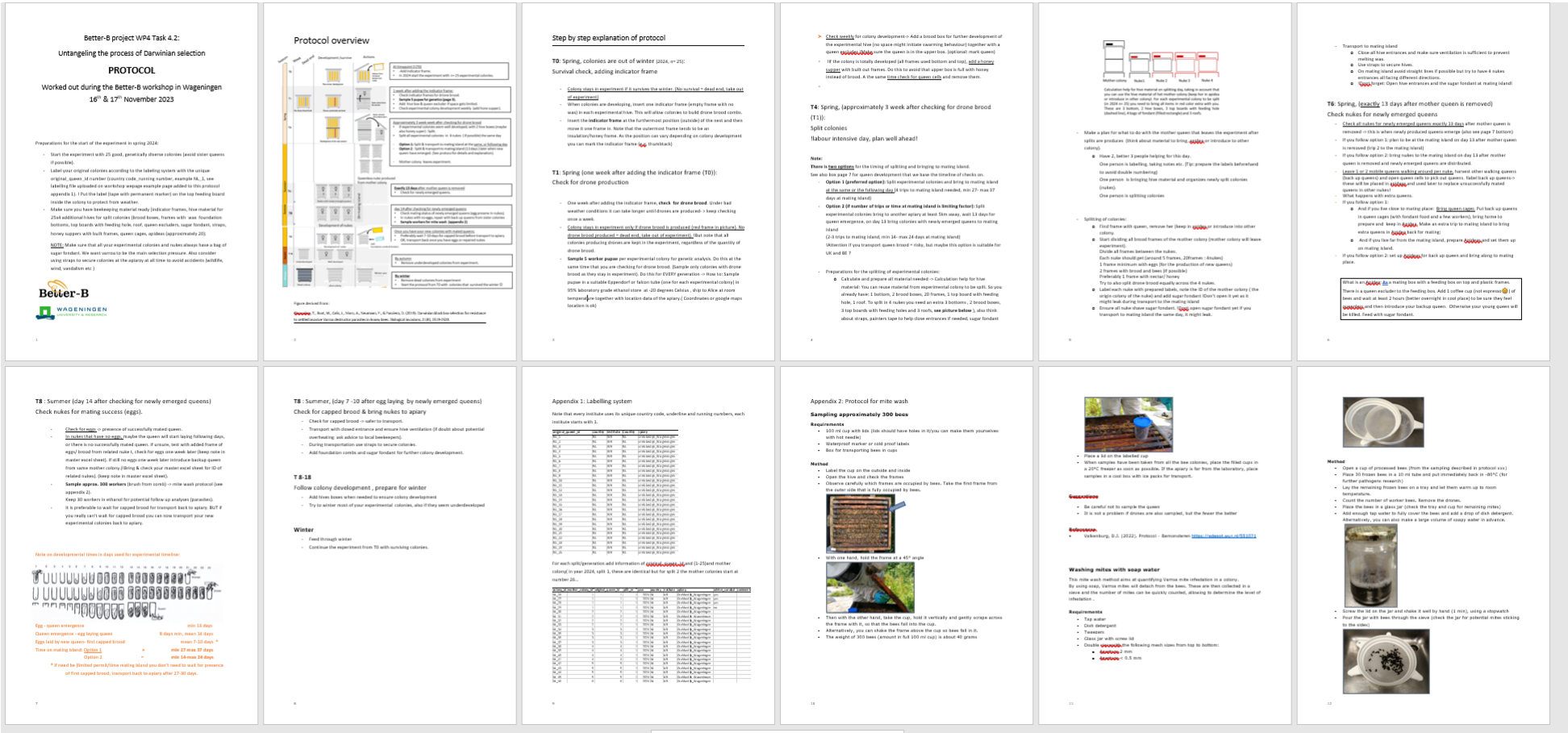
Figure derived from:

Blacquière, T., Boot, W., Calis, J., Moro, A., Neumann, P., & Panziera, D. (2019). Darwinian black box selection for resistance to settled invasive Varroa destructor parasites in honey bees. Biological invasions, 21(8), 2519-2528.

Modified from:

Blacquière et al., 2019. Darwinian black box selection for resistance to settled invasive Varroa destructor parasites in honey bees. *Biological invasions*, *21*(8), 2519-2528.

Result of the workshop



Better-B project WP4 Task 4.2:

Untangeling the process of Darwinian selection

PROTOCOL

Worked out during the Better-B workshop in Wageningen

16th & 17th November 2023

Preparations for the start of the experiment in spring 2024:

- Start the experiment with 25 good, genetically diverse colonies (avoid sister queens if possible).
- Label your original colonies according to the labeling system with the unique original_queen_id number (country code_running number; example NL_1; see labelling file uploaded on workshop wepage example page added to this protocol appendix 1). ! Put the label (tape with permanent marker) on the top feeding board inside the colony to protect from weather.
- Make sure you have beekeeping material ready (indicator frames, hive material for 25x6 additional hives for split colonies (brood boxes, frames with wax foundation bottoms, top boards with feeding hole, roof, queen excluders, sugar fondant, straps, honey suppers with built frames, queen cages, apideas (approximately 20).

NOTE: Make sure that all your experimental colonies and nukes always have a bag of sugar fondant. We want varroa to be the main selection pressure. Also consider using straps to secure colonies at the apiary at all time to avoid accidents (wildlife, wind, vandalism etc)

Better-B

WAGENINGEN UNIVERSITY & RESEARCH

Protocol overview

Step by step explanation of protocol

T0: Spring, colonies are out of winter (2024, n= 25):
Survival check, adding indicator frame

- Colony stays in experiment if it survives the winter; (No survival = dead end, take out of experiment)
- When colonies are developing, insert one indicator frame (empty frame with no wax) in each experimental hive. This will allow colonies to build drone brood combs.
- Insert the **indicator frame** at the furthermost position (outside) of the nest and then move it one frame in. Note that the outermost frame tends to be an insulation/honey frame. As the position can vary depending on colony development you can mark the indicator frame (e.g. thumbtack)

T1: Spring (one week after adding the indicator frame (T0)):
Check for drone production

- One week after adding the indicator frame, **check for drone brood**. Under bad weather conditions it can take longer until drones are produced -> keep checking once a week.
- Colony stays in experiment only if drone brood is produced (red frame in picture). No drone brood produced = dead end, take out of experiment). (But note that all colonies producing drones are kept in the experiment, regardless of the quantity of drone brood.
- **Sample 1 worker pupae** per experimental colony for genetic analysis. Do this at the same time that you are checking for drone brood. (Sample only colonies with drone brood as they stay in experiment). Do this for EVERY generation -> How to: Sample pupae in a suitable Eppendorf or falcon tube (one for each experimental colony) in 95% laboratory grade ethanol store at -20 degrees Celsius , drip to Alice at room temperature together with location data of the apiary.(Coordinates or google maps location is ok)

- Check weekly for colony development-> Add a brood box for further development of the experimental hive (no space might initiate swarming behaviour) together with a queen excluder (Note sure the queen is in the upper box. (optional: mark queen)
- IF the colony is totally developed (all frames used bottom and top), add a honey supper with built out frames. Do this to avoid that upper box is full with honey instead of brood. A the same time check for queen cells and remove them.

T4: Spring, (approximately 3 week after checking for drone brood (T1)):
Split colonies
!labour intensive day, plan well ahead!

Note:
There is two options for the timing of splitting and bringing to mating island.
See also box page 7 for queen development that we base the timeline of checks on.

- **Option 1 (preferred option):** Split experimental colonies and bring to mating island at the same or the following day (4 trips to mating island needed, min 27- max 37 days at mating island)
- **Option 2 (if number of trips or time at mating island is limiting factor):** Split experimental colonies bring to another apiary at least 5km away, wait 13 days for queen emergence, on day 13 bring colonies with newly emerged queens to mating island
  (2-3 trips to mating island, min 14- max 24 days at mating island)
  !Attention If you transport queen brood = risky, but maybe this option is suitable for UK and BE ?

- Preparations for the splitting of experimental colonies:
  - Calculate and prepare all material needed -> Calculation help for hive material: You can reuse material from experimental colony to be split. So you already have: 1 bottom, 2 brood boxes, 20 frames, 1 top board with feeding hole, 1 roof. To split in 4 nukes you need an extra 3 bottoms , 2 brood boxes, 3 top boards with feeding holes and 3 roofs, **see picture below**), also think about straps, painters tape to help close entrances if needed, sugar fondant

- Make a plan for what to do with the mother queen that leaves the experiment after splits are produces (think about material to bring, access or introduce to other colony).
  - Have 2, better 3 people helping for this day.
    One person is labelling, taking notes etc. (Tip: prepare the labels beforehand to avoid double numbering)
    One person. is bringing hive material and organizes newly split colonies (nukes).
    One person is splitting colonies
- Splitting of colonies:
  - Find frame with queen, remove her (keep in cage or introduce into other colony.
  - Start dividing all brood frames of the mother colony (mother colony will leave experiment).
    Divide all frames between the nukes.
    Each nuke should get (around 5 frames, 2)Frames :-4nukes)
    1 frame minimum with eggs (for the production of new queens)
    2 frames with brood and bees (if possible)
    Preferably 1 frame with nectar/ honey
    Try to also split drone brood equally across the 4 nukes.
  - Label each nuke with prepared labels, note the ID of the mother colony (the origin colony of the nuke) and add sugar fondant !Don't open it yet as it might leak during transport to the mating island
  - Ensure all nuke shave sugar fondant. Open sugar fondant yet if you transport to mating island the same day, it might leak.

- Transport to mating island
  - Close all hive entrances and make sure ventilation is sufficient to prevent melting wax.
  - Use straps to secure hives.
  - On mating island avoid straight lines if possible but try to have 4 nukes entrances all facing different directions.
  - Don't forget: Open hive entrances and the sugar fondant at mating island!

T5: Spring, (exactly 13 days after mother queen is removed)
Check nukes for newly emerged queens

- Check all nukes for newly emerged queens exactly 13 days after mother queen is removed -> this is when newly produced queens emerge (also see page 7 bottom)
- If you follow option 1: plan to be at the mating island on day 13 after mother queen is removed (trip 2 to the mating island)
- If you follow option 2: bring nukes to the mating island on day 13 after mother queen is removed and newly emerged queens are distributed.
- Leave 1 or 2 mobile queens walking around per nuke, harvest other walking queens (back up queens) and open queen cells to pick out queens. Label back up queens-> these will be placed in nukes and used later to replace unsuccessfully mated queens in other nukes!
- What happens with extra queens.
- If you follow option 1:
  - And if you live close to mating place: Bring queen cages. Put back up queens in queen cages (with fondant food and a few workers), bring home to prepare and keep in fridge. Make an extra trip to mating island to bring extra queens in fridge back for mating;
  - And if you live far from the mating island, prepare nucleus and set them up on mating island.
- If you follow option 2: set up nucleus for back up queen and bring along to mating place.

What is an nucleus: As a mating box with a feeding box on top and plastic frames. There is a queen excluder to the feeding box. Add 1 coffee cup (not espresso) of bees and wait at least 2 hours (better overnight in cool place) to be sure they feel queenless and then introduce your backup queen. Otherwise your young queen will be killed. Feed with sugar fondant.

T8 : Summer (day 14 after checking for newly emerged queens)
Check nukes for mating success (eggs).

- Check for eggs -> presence of successfully mated queen.
- In nukes that have no eggs, maybe the queen will start laying following days, or there is no successfully mated queen. If unsure, test with added frame of eggs/ brood from related nuke t, check for eggs one week later (keep note in master excel sheet). If still no eggs one week later introduce backup queen from same mother colony.(!Bring & check your master excel sheet for ID of related nukes). (keep note in master excel sheet).
- **Sample approx. 100 workers** (brush from comb) -> mite wash protocol (see appendix 2).
  Keep 30 workers in ethanol for potential follow-up analyses (parasites).
- It is preferable to wait for capped brood for transport back to apiary. BUT if you really can't wait for capped brood you can now transport your new experimental colonies back to apiary.

Note on developmental times in days used for experimental timeline:

Egg - queen emergence — min 15 days
Queen emergence - egg laying queen — 8 days min, mean 16 days
Eggs laid by new queen- first capped brood — mean 7-10 days *
Time on mating Island: Option 1 — min 27 max 37 days
Option 2 — min 14 max 24 days

* If need be (limited permit/time mating Island you don't need to wait for presence of first capped brood, transport back to apiary after 27-30 days.

T8 : Summer, (day 7 -10 after egg laying by newly emerged queens)
Check for capped brood & bring nukes to apiary

- Check for capped brood -> safer to transport.
- Transport with closed entrance and ensure hive ventilation (if doubt about potential overheating: ask advice to local beekeepers).
- During transportation use straps to secure colonies.
- Add foundation combs and sugar fondant for further colony development.

T 8-18
Follow colony development , prepare for winter

- Add hives boxes when needed to ensure colony development
- Try to winter most of your experimental colonies, also if they seem underdeveloped

Winter

- Feed through winter
- Continue the experiment from T0 with surviving colonies.

Appendix 1: Labelling system

Note that every institute uses its unique country code, underline and running numbers, each institute starts with 1.

For each split/generation add information of original_hive_id and (1-20)and mother colony(in year 2024, split 1, these are identical but for split 2 the mother colonies start at number 26..

Appendix 2: Protocol for mite wash

Sampling approximately 300 bees

Requirements

- 100 ml cup with lids (lids should have holes in it/you can make them yourselves with hot needle)
- Waterproof marker or cold proof labels
- Box for transporting bees in cups

Method

- Label the cup on the outside and inside
- Open the hive and check the frames
- Observe carefully which frames are occupied by bees. Take the first frame from the outer side that is fully occupied by bees.

- With one hand, hold the frame at a 45° angle

- Then with the other hand, take the cup, hold it vertically and gently scrape across the frame with it, so that the bees fall into the cup.
- Alternatively, you can shake the frame above the cup so bees fall in it.
- The weight of 300 bees (amount in full 100 ml cup) is about 40 grams

- Place a lid on the labelled cup
- When samples have been taken from all the bee colonies, place the filled cups in a 20°C freezer as soon as possible. If the apiary is far from the laboratory, place samples in a cool box with ice packs for transport.

Precautions

- Be careful not to sample the queen
- It is not a problem if drones are also sampled, but the fewer the better

Literature.

- Valkenburg, D.J. (2022). Protocol - Bemonsteren https://edepot.wur.nl/593073

Washing mites with soap water

This mite wash method aims at quantifying Varroa mite infestation in a colony.
By using soap, Varroa mites will detach from the bees. These are then collected in a sieve and the number of mites can be quickly counted, allowing to determine the level of infestation .

Requirements

- Tap water
- Dish detergent
- Tweezers
- Glass jar with screw lid
- Double stacked fine following mesh sizes from top to bottom:
  - Aperture 2 mm
  - Aperture < 0.5 mm

Method

- Open a cup of processed bees (from the sampling described in protocol xxx)
- Place 20 frozen bees in a 10 ml tube and put immediately back in -80°C (for further pathogenic research)
- Lay the remaining frozen bees on a tray and let them warm up to room temperature.
- Count the number of worker bees. Remove the drones.
- Place the bees in a glass jar (check the tray and cup for remaining mites)
- Add enough tap water to fully cover the bees and add a drop of dish detergent. Alternatively, you can also make a large volume of soapy water in advance.

- Screw the lid on the jar and shake it well by hand (1 min), using a stopwatch
- Pour the jar with bees through the sieve (check the jar for potential mites sticking to the sides)

Task 4.2: Untangling the process of Darwinian selection

- All partners have a sufficient number of colonies (>30) as of September 2024

Partner	Country	Present at last meeting	Number of mother colonies that were split	Number of daugther colonies (or splits)	Number of succesfully mated colonies	Number of colonies at last visit	Number of colonies that might be weak
IRIAF	ES	Antonio		100		51	0
USAMV	RO	Claudia; Alexandru	30	74	63	57	0
UCOI	PT	Nuno	18	72	42	33	8
IPB	PT	Ana Rita	23	92	73	65	9
TNTU	UK	Luke; Martin; Paul				34	0
UGENT	BE	Emma; Ellen	25	100	80	76	8
NB	NO	Linn; Bjorn	24	65	60	57	1
WR	NL	Jolanda	25	96	81	80	5
MLU	DE	Robert	25	100	90	90	0

Local adaptation by darwinian selection

Research questions:

What are the characteristics of a Darwinian colony?

What is the impact of mobility of beekeeping sector?

1. **Genetic characterization of established D-colonies**
2. **Follow-up colonies during process D-selection**
   - phenotypic data: colony strength, honey yield
   - genome sequencing: candidate genes associated with colony survival
   - hive monitoring technologies: BEEP base
   - accelerometer/electromagnetic shaker: vibrational signature
3.

Local adaptation by darwinian selection

Research questions:

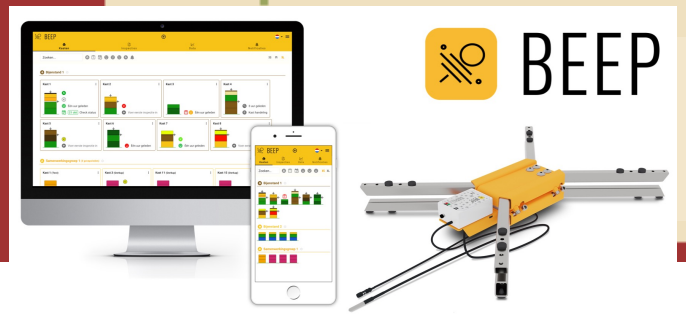
What are the characteristics of a Darwinian colony?

What is the impact of mobility of beekeeping sector?

1 **Genetic characterization of established D-colonies**

2 **Follow-up colonies during process D-selection**

- phenotypic data: colony strength, honey yield
- genome sequencing: candidate genes associated with colony survival
- hive monitoring technologies: BEEP base
- accelerometer/electromagnetic shaker: vibrational signature



weight, temperature, sound
-> common pattern?

Local adaptation by darwinian selection

Martin Bencsik
Luke Chamberlain

Research questions:

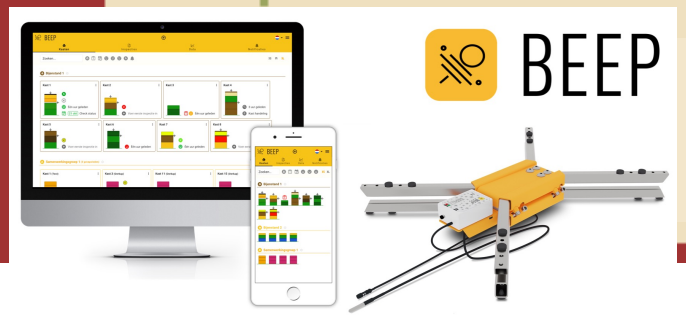
What are the characteristics of a Darwinian colony?

What is the impact of mobility of beekeeping sector?

1 **Genetic characterization of established D-colonies**

2 **Follow-up colonies during process D-selection**

- phenotypic data: colony strength, honey yield
- genome sequencing: candidate genes associated with colony survival
- hive monitoring technologies: BEEP base
- accelerometer/electromagnetic shaker: vibrational signature



weight, temperature, sound
-> common pattern?

Local adaptation by darwinian selection

Martin Bencsik
Luke Chamberlain

Research questions:

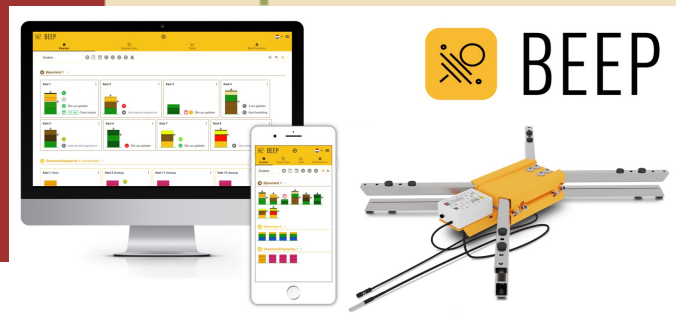
What are the characteristics of a Darwinian colony?

What is the impact of mobility of beekeeping sector?

1 **Genetic characterization of established D-colonies**

2 **Follow-up colonies during process D-selection**

- phenotypic data: colony strength, honey yield
- genome sequencing: candidate genes associated with colony survival
- hive monitoring technologies: BEEP base
- accelerometer/electromagnetic shaker: vibrational signature



Local adaptation by darwinian selection

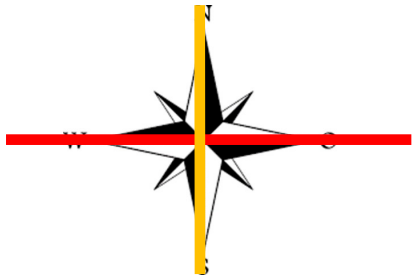
Research questions:

What are the characteristics of a Darwinian colony?

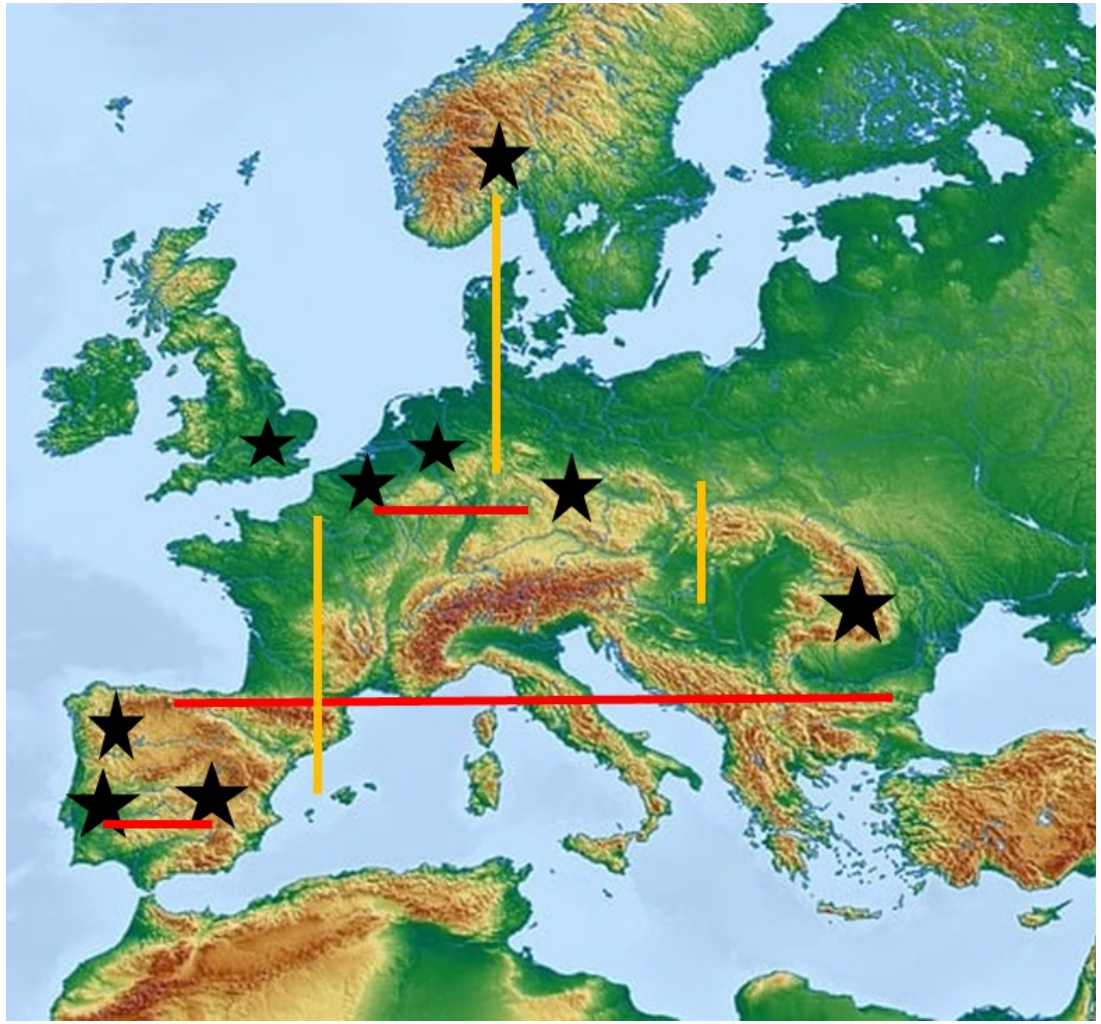
What is the impact of mobility of beekeeping sector?

1. **Genetic characterization of established D-colonies**
2. **Follow-up colonies during process D-selection**
   - phenotypic data: colony strength, honey yield
   - genome sequencing: candidate genes associated with colony survival
   - hive monitoring technologies: BEEP base
   - accelerometer/electromagnetic shaker: vibrational signature
3. **Testing the genotype-environment interaction theorem**

Translocation experiment



3 North- South
3 East – West



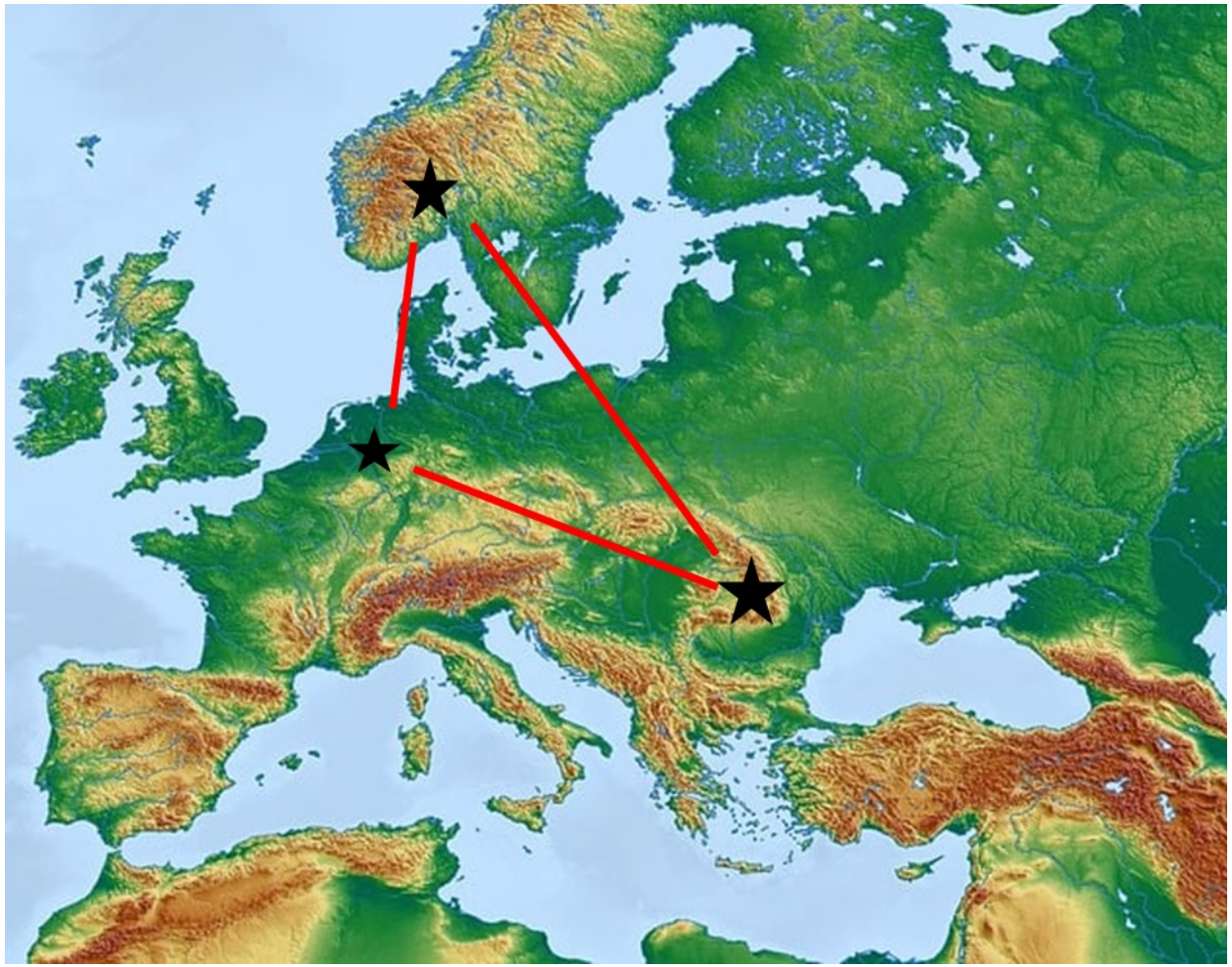
- Queens of locally adapted conventionally managed colonies are exchanged
- varroa treated colonies

-> test importance of local adaptation (local climate)

Translocation experiment

- Queens of established DBB colonies are exchanged (WR, NB, USAMV)

-> test importance adaptation to local varroa



Summary importance of this work in Better-b

- **Innovation:**

- Developing a protocol for **European wide beekeeping with Darwin**.
- > Testing characteristics of a successful DBB colony.
- > Potential for being applied amongst local bekeeper


Better-B

Thank you

Tjeerd Blacquiere
(In pension, Wageningen University & Research)

Inbuzz BV:
Johan Calis
Willem Boot
Pam van Stratum

This work was supported by the Better-B project, which has received funding from the European Union, the Swiss State Secretariat for Education, Research and Innovation (SERI) and UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee.

UK Research and Innovation

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation