

Documentation for Precision Beekeeping Ontology (PBO)

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1 Introduction

This documentation contains technical information about the Precision Beekeeping Ontology (PBO) developed to represent knowledge in beekeeping domain, particularly precision beekeeping (PB). The PBO ontology targets the researchers, agriculturalists particularly beekeepers, software developers and ontology engineering community. The PBO ontology covers the following areas in hive and colony health management in precision beekeeping: observation such as temperature, weight and humidity observations that represent actual measurement events and its results. It covers observable property such as temperature, weight and humidity that represents what can be measured. It covers devices used in PB such as smart devices, hives, power supply system and network router. Also, it covers the monitoring system and alert

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about connectivity and power. It covers hive and monitoring system status. It covers about bee and their roles.

This documentation is organized as follows: Section 2 contains PBO ontology metadata; Section 3 gives information about reused external thesauri and ontologies; Section 4 is about PBO ontology structure; Section 5 explains about constraints on properties in PBO ontology; Section 6 talks about SPARQL queries and results of PBO ontology; Section 7 concludes the documentation and there is appendices in the end of this document.

2 PBO ontology metadata

- *Ontology name*: The name given to the developed ontology is Precision Beekeeping Ontology (PBO).
- *Version*: This is the first version (V1.0) of the PBO ontology.
- *Ontology availability*: The PBO ontology is available at <https://github.com/paulmushi0018/Precision-Beekeeping-Ontology-PBO->
- *License*: The PBO ontology is released under Creative Commons licenses (CC BY-SA)¹
- *Language and tools used*: The tool used to develop ontology is Protégé² 5.6.5, which supports OWL 2 (Web Ontology Language), Resource Description Framework (RDF) and Description Logic (DL). The SPARQL³ queries were done in Apache Jena Fuseki Server 5.4.0 and Logical consistency was checked using HermiT 1.4.3.456 reasoner in Protégé. Visualization tool, WebVOWL⁴ was used.

3 Reused external thesauri and ontologies

The PBO ontology reused the concepts and relations from DOLCE+DnS Ultralite (DUL) upper ontology⁵, SOSA Module (Sensors, Observations, Samples and Actuators) in Semantic Sensor network ontology (SSN)⁶, AGROVOC⁷

¹<https://creativecommons.org/licenses/by-sa/4.0/>

²<https://protege.stanford.edu/software.php#desktop-protege>

³https://sparql.dev/article/SPARQL_and_ontology_development.html

⁴<https://service.tib.eu/webvowl/>

⁵<http://www.ontologydesignpatterns.org/ont/dul/DUL.owl>

⁶<https://w3c.github.io/sdw-sosa-ssn/ssn/>

⁷https://agrovoc.fao.org/browse/agrovoc/en/page/c_529

Multilingual Thesaurus and the General Multilingual Environmental Thesaurus (GEMET⁸), for example “c_8872” for “Apiary_” and all other classes defined in Protégé with URI in external vocabulary were annotated by *rdfs:label* for readability. This can be seen in Figure 1 for the term Apiary_ and Bee-Colony_ that they have external link to AGROVOC thesaurus.

Figure 1: Class hierarchy and visualization of the PBO ontology using the WebVOWL tool

As depicted in Figure 2, metrics of PBO ontology in Protégé are axioms, logical axioms count, declarative axioms count, class count, object property count, data property count, individual count and annotation property count.

Figure 2: Metrics of the PBO ontology from the Protégé

- PBO ontology has 1081 axioms, whereby 696 axioms are logical and 355 axioms are declarative.
- PBO ontology has 188 concepts or terms that appear as classes in Protégé, which indicates the concepts that have been covered in the PB domain.
- The object property count in PBO ontology is 70, which defines the relationship between classes. For example, the object property that links the “Observation” class and the “BeeHive” class is shown in Figure 3 “hasFeatureOfInterest” which was reused from SSN/SOSA. Also, some of object properties are seen in Figure 4 as defined in the Protégé.

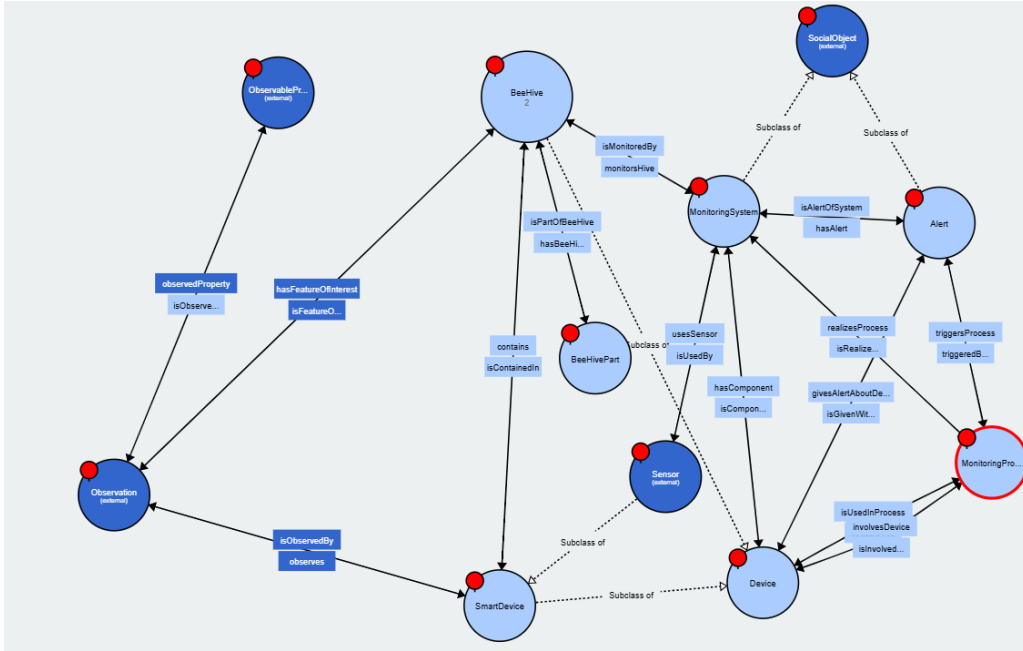


Figure 3: Visualization in WebVOWL tool of the object properties such as hasFeatureOfInterest between the Observation class and the BeeHive class.

- The data property count is 23 in the PBO ontology and some of them are seen in Figure 5.
- The individual count is 74 in PBO ontology as seen in Table 1 and Table 2, which contains about beehive metrics that include 2 hives (Schwartau and Wurzburg), 48 internal temperature readings of Schwartau hive

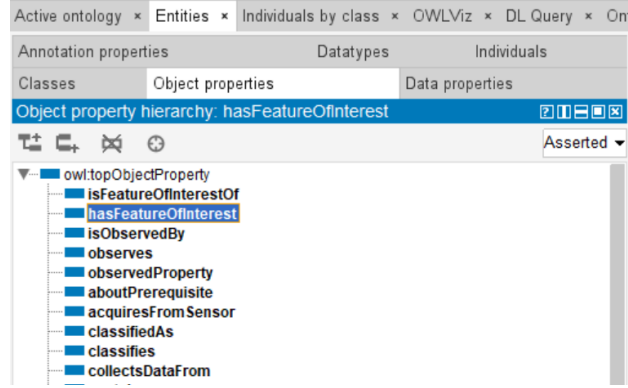


Figure 4: Snippet of Object Property Hierarchy in Protégé for PBO Ontology

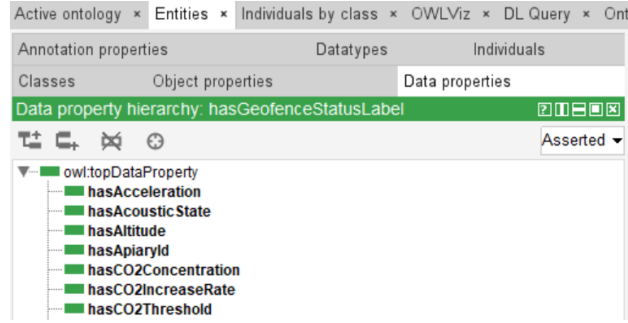


Figure 5: Snippet of Data Property Hierarchy in Protégé for PBO Ontology

and 24 hive weight readings of Schwartau and Wurzburg hives from Kaggle dataset repository⁹ as seen in Figure 6.

5 Constraints on properties in PBO ontology

To ensure the correct reasoning of the PBO ontology, we specified constraints on the properties. For example, the value datatype constraints show that the *WeightObservation* class can contain individual *WeightObs1* specified under the data property *hasWeight* with value *50.55* as double datatype and not otherwise as seen in Figure 7.

We also specified the domain and range restrictions on the object properties for example *hasFeatureOfInterest* object property with the domain *Observation* class and the range *BeeHive* class.

In specifying restrictions on data properties, we specified value datatypes,

⁹<https://www.kaggle.com/datasets/se18m502/bee-hive-metrics/data>

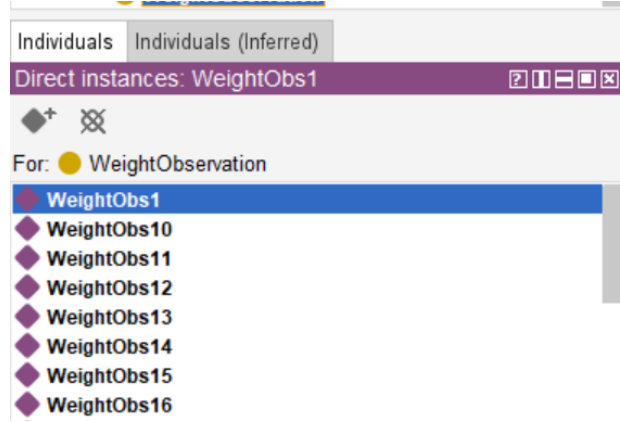


Figure 6: Snippet of individuals (instances) in Protégé for PBO Ontology



Figure 7: Snippet of data Property restrictions in Protégé for PBO Ontology

domain and range restrictions such as hasWeight data property link between BeeHive class as domain and xsd:double as range.

6 SPARQL queries and results of PBO ontology

The PBO ontology was evaluated based on the pre-defined competence questions (CQs) that were 6 based on the internal temperature and hive weight data. Using SPARQL queries in the Apache Jena Fuseki server after being set locally as shown in Figure 8, we successfully evaluated the ontology based on 6 CQs. Figure 9 shows the total number of triples uploaded 1082, from the PBO ontology, from which CQ1 (For each hive, what is its most recent recorded weight?) is illustrated in Figure 10.

Figure 11 illustrates instances of the results for CQ1 for corresponding query in Figure 10 which gives the latest recorded weight per hive which are 50.55 and 52.38 for Schwartau and Wurzburg respectively . The other CQs 2 to 6 for SPARQL queries and results are available in Appendices A to J.

```

Microsoft Windows [Version 10.0.26100.7462]
(c) Microsoft Corporation. All rights reserved.

C:\Users\paulk>java -version
java version "24.0.1" 2025-04-15
Java(TM) SE Runtime Environment (build 24.0.1+9-30)
Java HotSpot(TM) 64-Bit Server VM (build 24.0.1+9-30, mixed mode, sharing)

C:\Users\paulk>cd C:\apache-jena-fuseki-5.4.0

C:\apache-jena-fuseki-5.4.0>fuseki-server --update -mem /ds_pbo
15:03:20 INFO Server      :: Apache Jena Fuseki 5.4.0
15:03:20 INFO Config      :: Fuseki Base = C:\apache-jena-fuseki-5.4.0\run
15:03:20 INFO Config      :: Load configuration: file:///C:/apache-jena-fuseki-5.4.0/run/configuration/ds.ttl
15:03:20 INFO Config      :: Database: /ds_pbo
15:03:20 INFO Config      :: Database: /ds
15:03:20 INFO Config      :: UI Base = fuseki-server.jar
15:03:21 ERROR Server      :: Expected only one dataset in the DataAccessPointRegistry
15:03:21 INFO Server      :: Database: in-memory
15:03:21 INFO Server      :: Path = /ds
15:03:21 INFO Server      :: Path = /ds_pbo
15:03:21 INFO Server      :: Memory: 4.0 GiB
15:03:21 INFO Server      :: Java: 24.0.1
15:03:21 INFO Server      :: OS: Windows 11 10.0 amd64
15:03:21 INFO Server      :: PID: 16468
15:03:21 INFO Shiro       :: Shiro configuration: file:C:\apache-jena-fuseki-5.4.0\run\shiro.ini
15:03:21 INFO Server      :: Start Fuseki (http=3030)

```

Figure 8: Setting the Apache Jena Fuseki Server for Ontology Evaluation

/ds_pbo

[query](#)
[add data](#)
[edit](#)
[info](#)

Upload files /ds_pbo/data

Load data into the default graph of the currently selected dataset, or the given named graph. You may upload any RDF format, such as Turtle, RDF/XML or TRIG.

Dataset graph name

Leave blank for default graph

Files to upload

[+ select files](#)
[upload all](#)

1/1

name	size	speed	status	actions
revisedPBO.rdf	161.37kb	161.56kb/s	<div>100.00</div> <div> <div></div> <div>Triples uploaded: 1082</div> </div>	upload now remove

Figure 9: Triples uploaded in Apache Jena Fuseki server for running SPARQL queries

Table 1: Sample weight observations for Wurzburg and Schwartau hives

Instance	Hive	Hive ID	Recorded Timestamp	Weight (kg)
WeightObs1	Wurzburg	Wurzburg1	2017-01-01T13:00:00	52.63
WeightObs2	Wurzburg	Wurzburg1	2017-01-02T01:00:00	52.67
WeightObs3	Wurzburg	Wurzburg1	2017-01-02T13:00:00	52.70
WeightObs4	Wurzburg	Wurzburg1	2017-01-03T01:00:00	52.70
WeightObs5	Wurzburg	Wurzburg1	2017-01-03T13:00:00	52.63
WeightObs6	Wurzburg	Wurzburg1	2017-01-04T01:00:00	52.63
WeightObs7	Wurzburg	Wurzburg1	2017-01-04T13:00:00	52.67
WeightObs8	Wurzburg	Wurzburg1	2017-01-05T01:00:00	52.60
WeightObs9	Wurzburg	Wurzburg1	2017-01-05T13:00:00	52.57
WeightObs10	Wurzburg	Wurzburg1	2017-01-06T01:00:00	52.67
WeightObs11	Wurzburg	Wurzburg1	2017-01-06T13:00:00	52.89
WeightObs12	Wurzburg	Wurzburg1	2017-01-07T01:00:00	52.38
WeightObs13	Schwartau	Schwartau1	2017-01-01T13:00:00	50.74
WeightObs14	Schwartau	Schwartau1	2017-01-02T01:00:00	50.70
WeightObs15	Schwartau	Schwartau1	2017-01-02T13:00:00	50.61
WeightObs16	Schwartau	Schwartau1	2017-01-03T01:00:00	50.74
WeightObs17	Schwartau	Schwartau1	2017-01-03T13:00:00	50.80
WeightObs18	Schwartau	Schwartau1	2017-01-04T01:00:00	50.65
WeightObs19	Schwartau	Schwartau1	2017-01-04T13:00:00	50.41
WeightObs20	Schwartau	Schwartau1	2017-01-05T01:00:00	50.17
WeightObs21	Schwartau	Schwartau1	2017-01-05T13:00:00	50.05
WeightObs22	Schwartau	Schwartau1	2017-01-06T01:00:00	49.88
WeightObs23	Schwartau	Schwartau1	2017-01-06T13:00:00	50.46
WeightObs24	Schwartau	Schwartau1	2017-01-07T01:00:00	50.55



Figure 10: SPARQL query for Competence Question 1 (CQ1) in Jena Fuseki Server for Ontology Evaluation

hive	time	weight
1<http://www.semanticweb.org/paulk/ontologies/2025/10/reviseadPBO#Schwartau>	"2017-01-07T01:00:00"^^<http://www.w3.org/2001/XMLSchema#time>	"50.55"^^<http://www.w3.org/2001/XMLSchema#float>
2<http://www.semanticweb.org/paulk/ontologies/2025/10/reviseadPBO#Wurzburg>	"2017-01-07T01:00:00"^^<http://www.w3.org/2001/XMLSchema#time>	"52.38"^^<http://www.w3.org/2001/XMLSchema#float>

Figure 11: SPARQL query results for Competence Question 1 (CQ1) in Jena Fuseki Server for Ontology Evaluation

Table 2: Sample internal temperature observations for the Schwartau hive

Instance	Hive	Hive ID	Recorded Timestamp	Internal Temperature (°C)
InTemperatureObs1	Schwartau	Schwartau1	2017-01-01T14:15:00	12.34
InTemperatureObs2	Schwartau	Schwartau1	2017-01-01T15:15:00	12.38
InTemperatureObs3	Schwartau	Schwartau1	2017-01-01T16:15:00	15.73
InTemperatureObs4	Schwartau	Schwartau1	2017-01-01T17:15:00	17.63
InTemperatureObs5	Schwartau	Schwartau1	2017-01-01T18:15:00	13.35
InTemperatureObs6	Schwartau	Schwartau1	2017-01-01T19:15:00	13.93
InTemperatureObs7	Schwartau	Schwartau1	2017-01-01T20:15:00	12.52
InTemperatureObs8	Schwartau	Schwartau1	2017-01-01T21:15:00	20.56
InTemperatureObs9	Schwartau	Schwartau1	2017-01-01T22:15:00	19.91
InTemperatureObs10	Schwartau	Schwartau1	2017-01-01T23:15:00	19.99
InTemperatureObs11	Schwartau	Schwartau1	2017-01-02T00:15:00	18.24
InTemperatureObs12	Schwartau	Schwartau1	2017-01-02T01:15:00	13.47
InTemperatureObs13	Schwartau	Schwartau1	2017-01-02T02:15:00	13.20
InTemperatureObs14	Schwartau	Schwartau1	2017-01-02T03:15:00	14.86
InTemperatureObs15	Schwartau	Schwartau1	2017-01-02T04:15:00	12.34

Continued on next page

Instance	Hive	Hive ID	Recorded Timestamp	Internal Temperature (°C)
InTemperatureObs16	Schwartau	Schwartau1	2017-01-02T05:15:00	12.77
InTemperatureObs17	Schwartau	Schwartau1	2017-01-02T06:15:00	13.90
InTemperatureObs18	Schwartau	Schwartau1	2017-01-02T07:15:00	15.16
InTemperatureObs19	Schwartau	Schwartau1	2017-01-02T08:15:00	11.72
InTemperatureObs20	Schwartau	Schwartau1	2017-01-02T09:15:00	12.75
InTemperatureObs21	Schwartau	Schwartau1	2017-01-02T10:15:00	12.52
InTemperatureObs22	Schwartau	Schwartau1	2017-01-02T11:15:00	11.50
InTemperatureObs23	Schwartau	Schwartau1	2017-01-02T12:15:00	12.92
InTemperatureObs24	Schwartau	Schwartau1	2017-01-02T13:15:00	14.60
InTemperatureObs25	Schwartau	Schwartau1	2017-01-02T14:15:00	11.91
InTemperatureObs26	Schwartau	Schwartau1	2017-01-02T15:15:00	12.16
InTemperatureObs27	Schwartau	Schwartau1	2017-01-02T16:15:00	11.63
InTemperatureObs28	Schwartau	Schwartau1	2017-01-02T17:15:00	11.43
InTemperatureObs29	Schwartau	Schwartau1	2017-01-02T18:15:00	11.03
InTemperatureObs30	Schwartau	Schwartau1	2017-01-02T19:15:00	10.60
InTemperatureObs31	Schwartau	Schwartau1	2017-01-02T20:15:00	11.67
InTemperatureObs32	Schwartau	Schwartau1	2017-01-02T21:15:00	13.48
InTemperatureObs33	Schwartau	Schwartau1	2017-01-02T22:15:00	20.08
InTemperatureObs34	Schwartau	Schwartau1	2017-01-02T23:15:00	15.84
InTemperatureObs35	Schwartau	Schwartau1	2017-01-03T00:15:00	16.57
InTemperatureObs36	Schwartau	Schwartau1	2017-01-03T01:15:00	15.75
InTemperatureObs37	Schwartau	Schwartau1	2017-01-03T02:15:00	19.50
InTemperatureObs38	Schwartau	Schwartau1	2017-01-03T03:15:00	12.33
InTemperatureObs39	Schwartau	Schwartau1	2017-01-03T04:15:00	12.67
InTemperatureObs40	Schwartau	Schwartau1	2017-01-03T05:15:00	11.43
InTemperatureObs41	Schwartau	Schwartau1	2017-01-03T06:15:00	14.14
InTemperatureObs42	Schwartau	Schwartau1	2017-01-03T07:15:00	11.00
InTemperatureObs43	Schwartau	Schwartau1	2017-01-03T08:15:00	15.28
InTemperatureObs44	Schwartau	Schwartau1	2017-01-03T09:15:00	15.49
InTemperatureObs45	Schwartau	Schwartau1	2017-01-03T10:15:00	15.24
InTemperatureObs46	Schwartau	Schwartau1	2017-01-02T11:15:00	15.62
InTemperatureObs47	Schwartau	Schwartau1	2017-01-02T12:15:00	20.91
InTemperatureObs48	Schwartau	Schwartau1	2017-01-02T13:15:00	15.63

7 Conclusion

This documentation gives the technical details of the PBO ontology about metadata, reused external links, the structure of the ontology, constraints specified in PBO ontology and SPARQL queries and results during evaluation. The PBO ontology can be extended to improve interoperability by including external links to the concepts and object properties from other ontologies. Also, PBO ontology can be extended by considering more parameters such as acoustic sound, humidity, CO2 concentration and geo position as the real-world data from hives connected with sensors in the apiary.

Appendices

A : CQ 2: On which days did each hive experience strong daily nectar intake, defined as a daily weight increase above a threshold?

```
/ds_pbo/ JSON Turtle
1 PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
2 PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
3 PREFIX pbo: <http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#>
4 PREFIX sosa: <http://www.w3.org/ns/sosa/>
5 SELECT ?hive ?day ?startWeight ?endWeight (?endWeight - ?startWeight AS ?dailyChange)
6 WHERE {(SELECT ?hive ?day (MIN(?t) AS ?startTime) (MAX(?t) AS ?endTime)
7 WHERE {
8   ?obs rdf:type pbo:WeightObservation ;
9   sosa:hasFeatureOfInterest ?hive ;
10  pbo:recordedAt ?t .
11  FILTER(
12    ?t >= "2017-01-01T00:00:00"^^xsd:dateTime && ?t < "2017-01-31T00:00:00"^^xsd:dateTime
13    BIND( xsd:date(?t) AS ?day )}
14  GROUP BY ?hive ?day}}
15 ?startObs rdf:type pbo:WeightObservation ;
16 sosa:hasFeatureOfInterest ?hive ;
17 pbo:recordedAt ?startTime ;
18 pbo:hasWeight ?startWeight .
19 ?endObs rdf:type pbo:WeightObservation ;
20 sosa:hasFeatureOfInterest ?hive ;
21 pbo:recordedAt ?endTime ;
22 pbo:hasWeight ?endWeight .
23 FILTER( (?endWeight - ?startWeight) > 0 )}
24 ORDER BY ?hive ?day
```

Figure 12: SPARQL query for CQ 2 in Apache Jena Fuseki Server

B : SPARQL query results for CQ 2

hive	day	startWeight	endWeight	dailyChange
2 <http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#Schwartau>	"2017-01-06"^^http://www.w3.org/2001/XMLSchema#date	"49.88"^^http://www.w3.org/2001/XMLSchema#float	"50.46"^^http://www.w3.org/2001/XMLSchema#float	"0.5799999999999999"
1 <http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#Schwartau>	"2017-01-03"^^http://www.w3.org/2001/XMLSchema#date	"50.74"^^http://www.w3.org/2001/XMLSchema#float	"50.8"^^http://www.w3.org/2001/XMLSchema#float	"0.05999999999999999"
4 <http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#Wurzburg>	"2017-01-04"^^http://www.w3.org/2001/XMLSchema#date	"52.63"^^http://www.w3.org/2001/XMLSchema#float	"52.67"^^http://www.w3.org/2001/XMLSchema#float	"0.03999999999999999"
3 <http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#Wurzburg>	"2017-01-02"^^http://www.w3.org/2001/XMLSchema#date	"52.67"^^http://www.w3.org/2001/XMLSchema#float	"52.7"^^http://www.w3.org/2001/XMLSchema#float	"0.03000000000000000"
5 <http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#Wurzburg>	"2017-01-06"^^http://www.w3.org/2001/XMLSchema#date	"52.67"^^http://www.w3.org/2001/XMLSchema#float	"52.89"^^http://www.w3.org/2001/XMLSchema#float	"0.21999999999999999"

Figure 13: SPARQL query results for CQ 2 in Apache Jena Fuseki Server

C : CQ 3: On which days did each hive experience a significant daily weight loss below a given threshold?

```

1 PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
2 PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
3 PREFIX pbo: <http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#>
4 PREFIX sosa: <http://www.w3.org/ns/sosa/>
5 SELECT ?hive ?day ?startWeight ?endWeight ?dailyChange
6 WHERE {{SELECT ?hive ?day (MIN(?t) AS ?startTime) (MAX(?t) AS ?endTime)
7 WHERE {
8   ?obs rdf:type pbo:WeightObservation ;
9   sosa:hasFeatureOfInterest ?hive ;
10  pbo:recordedAt ?t .
11  FILTER(
12    ?t >= "2017-01-01T00:00:00"^^xsd:dateTime && ?t < "2017-01-31T00:00:00"^^xsd:dateTime
13  )
14  BIND( xsd:date(?t) AS ?day )}
15  GROUP BY ?hive ?day}
16  ?startObs rdf:type pbo:WeightObservation ;
17  sosa:hasFeatureOfInterest ?hive ;
18  pbo:recordedAt ?startTime ;
19  pbo:hasWeight ?startWeight .
20  ?endObs rdf:type pbo:WeightObservation ;
21  sosa:hasFeatureOfInterest ?hive ;
22  pbo:recordedAt ?endTime ;
23  pbo:hasWeight ?endWeight .
24  FILTER( (?endWeight - ?startWeight) < 0 )}
25 ORDER BY ?hive ?day

```

Figure 14: SPARQL query for CQ 3 in Apache Jena Fuseki Server

D : SPARQL query results for CQ 3

hive	day	startWeight	endWeight	dailyChange
1<http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#Schwartau>	"2017-01-02"	"50.7"	"50.61"	-0.0900000000...
2<http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#Schwartau>	"2017-01-04"	"50.65"	"50.41"	-0.2400000000...
3<http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#Schwartau>	"2017-01-05"	"50.17"	"50.05"	-0.1200000000...
4<http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#Wurzburg>	"2017-01-03"	"52.7"	"52.63"	-0.0700000000...
5<http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#Wurzburg>	"2017-01-05"	"52.6"	"52.57"	-0.0300000000...

Figure 15: SPARQL query results for CQ 3 in Apache Jena Fuseki Server

E : CQ 4: Is the Schwartau hive maintaining stable internal hive temperature?

SPARQL Endpoint: /ds/query Content Type (SELECT): JSON

```

1 PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
2 PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
3
4 SELECT ?instance ?label
5 WHERE {
6   ?instance rdf:type <https://agrodoc.fao.org/browse/agrodoc/en/page/c_28279> .
7   FILTER NOT EXISTS {
8     ?instance rdf:type ?subclass .
9     ?subclass rdfs:subClassOf <https://agrodoc.fao.org/browse/agrodoc/en/page/c_28279> .
10    FILTER (?subclass != <https://agrodoc.fao.org/browse/agrodoc/en/page/c_28279>)
11  }
12  OPTIONAL {?instance rdfs:label ?label}
13 }
14

```

Table Response 10 results in 0.025 seconds

Figure 16: SPARQL query for CQ 4 in Apache Jena Fuseki Server

F : SPARQL query results for CQ 4

Table Response 14 results in 0.316 seconds					
time1	temp1	time2	temp2	time3	temp3
1"2017-01-01T19:15:00"	13.93	"2017-01-01T20:15:00"	12.52	"2017-01-01T21:15:00"	20.56
2"2017-01-01T20:15:00"	12.52	"2017-01-01T21:15:00"	20.56	"2017-01-01T22:15:00"	19.91
3"2017-01-01T21:15:00"	20.56	"2017-01-01T22:15:00"	19.91	"2017-01-01T23:15:00"	19.99
4"2017-01-02T10:15:00"	12.52	"2017-01-02T11:15:00"	11.5	"2017-01-02T12:15:00"	20.91
5"2017-01-02T10:15:00"	12.52	"2017-01-02T11:15:00"	15.62	"2017-01-02T12:15:00"	20.91
6"2017-01-02T11:15:00"	11.5	"2017-01-02T12:15:00"	20.91	"2017-01-02T13:15:00"	14.6
7"2017-01-02T11:15:00"	11.5	"2017-01-02T12:15:00"	20.91	"2017-01-02T13:15:00"	15.63
8"2017-01-02T11:15:00"	15.62	"2017-01-02T12:15:00"	20.91	"2017-01-02T13:15:00"	14.6
9"2017-01-02T11:15:00"	15.62	"2017-01-02T12:15:00"	20.91	"2017-01-02T13:15:00"	15.63
10"2017-01-02T12:15:00"	20.91	"2017-01-02T13:15:00"	14.6	"2017-01-02T14:15:00"	11.91
11"2017-01-02T12:15:00"	20.91	"2017-01-02T13:15:00"	15.63	"2017-01-02T14:15:00"	11.91

Figure 17: SPARQL query results for CQ 4 in Apache Jena Fuseki Server

G : CQ 5: Did the Schwartau hive experience rapid temperature drops (less than 2°C per hour), indicating weakening thermoregulation or disturbance?

```

SPARQL Endpoint: /ds_pbo/
Content Type (SELECT): JSON
Content Type (GRAPH): Turtle

1 PREFIX sosa: <http://www.w3.org/ns/sosa/>
2 PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
3 PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
4 PREFIX pbo: <http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#>
5 SELECT ?time1 ?temp1 ?time2 ?temp2 ?deltaTemp
6 WHERE {
7   ?obs1 a pbo:InternalTemperatureObservation ;
8   sosa:hasFeatureOfInterest pbo:Schwartau ;
9   pbo:recordedAt ?time1 ;
10  pbo:hasTemperature ?temp1 .
11  ?obs2 a pbo:InternalTemperatureObservation ;
12  sosa:hasFeatureOfInterest pbo:Schwartau ;
13  pbo:recordedAt ?time2 ;
14  pbo:hasTemperature ?temp2 .
15  # ensure obs2 is exactly 1 hour after obs1
16  FILTER(?time2 = ?time1 + "PT1H"^^xsd:duration)
17  # compute temperature change
18  BIND((?temp2 - ?temp1) AS ?deltaTemp)
19  # keep only strong drops
20  FILTER(?deltaTemp < -2.0)
21 }
22 ORDER BY ?time1

```

Figure 18: SPARQL query for CQ 5 in Apache Jena Fuseki Server

H : SPARQL query results for CQ 5

time1	temp1	time2	temp2	deltaTemp
1*2017-01-01T17:15:00	17.63	2017-01-01T18:15:00	13.35	-4.279999999999999e0
2*2017-01-02T00:15:00	18.24	2017-01-02T01:15:00	13.47	-4.769999999999999e0
3*2017-01-02T03:15:00	14.86	2017-01-02T04:15:00	12.34	-2.519999999999999e0
4*2017-01-02T07:15:00	15.16	2017-01-02T08:15:00	11.72	-3.439999999999999e0
5*2017-01-02T11:15:00	15.62	2017-01-02T12:15:00	12.92	-2.699999999999999e0
6*2017-01-02T12:15:00	20.91	2017-01-02T13:15:00	15.63	-5.279999999999999e0
7*2017-01-02T12:15:00	20.91	2017-01-02T13:15:00	14.6	-6.310000000000000e0
8*2017-01-02T13:15:00	14.6	2017-01-02T14:15:00	11.91	-2.689999999999999e0
9*2017-01-02T13:15:00	15.63	2017-01-02T14:15:00	11.91	-3.720000000000000e0
10*2017-01-02T22:15:00	20.08	2017-01-02T23:15:00	15.84	-4.239999999999999e0
11*2017-01-03T02:15:00	19.5	2017-01-03T03:15:00	12.33	-7.17e0

Figure 19: SPARQL query results for CQ 5 in Apache Jena Fuseki Server

I : CQ 6: Is the internal temperature showing a consistent upward or downward trend indicating cluster migration?

SPARQL Endpoint	Content Type (SELECT)	Content Type (GRAPH)
/ds_pbo/	JSON	Turtle
<pre> 1. PREFIX sosa: <http://www.w3.org/ns/sosa/> 2. PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> 3. PREFIX xsd: <http://www.w3.org/2001/XMLSchema#> 4. PREFIX pbo: <http://www.semanticweb.org/paulk/ontologies/2025/10/revisePBO#> 5. SELECT ?avgDay1 ?avgDay2 ?avgDay3 6. (?avgDay2 - ?avgDay1 AS ?trend1_Day2_Day1) 7. (?avgDay3 - ?avgDay2 AS ?trend2_Day3_Day2) 8. WHERE { 9. (SELECT (AVG(?temp) AS ?avgDay1) WHERE { 10. ?obs rdf:type pbo:InternalTemperatureObservation ; 11. sosa:hasFeatureOfInterest pbo:Schwartau ; 12. pbo:recordedAt ?time ; 13. pbo:hasTemperature ?temp . 14. FILTER(xsd:date(?time) = "2017-01-01"^^xsd:date) }) 15. (SELECT (AVG(?temp) AS ?avgDay2) WHERE { 16. ?obs rdf:type pbo:InternalTemperatureObservation ; 17. sosa:hasFeatureOfInterest pbo:Schwartau ; 18. pbo:recordedAt ?time ; 19. pbo:hasTemperature ?temp . 20. FILTER(xsd:date(?time) = "2017-01-02"^^xsd:date) }) 21. (SELECT (AVG(?temp) AS ?avgDay3) WHERE { 22. ?obs rdf:type pbo:InternalTemperatureObservation ; 23. sosa:hasFeatureOfInterest pbo:Schwartau ; 24. pbo:recordedAt ?time ; 25. pbo:hasTemperature ?temp . 26. FILTER(xsd:date(?time) = "2017-01-03"^^xsd:date) }) 27. } </pre>		

Figure 20: SPARQL query for CQ 6 in Apache Jena Fuseki Server

J : SPARQL query results for CQ 6

avgDay1	avgDay2	avgDay3	trend1_Day2_Day1	trend2_Day3_Day2
1*15.84e0	13.775555555555555e0	14.490909090909090e0	-2.058444444444444e0	0.7153535353535307e0

Figure 21: SPARQL query results for CQ 6 in Apache Jena Fuseki Server