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 main areas: bee (bee biodiversity and bee biology), beekeeping practices (beekeeping equipment, beekeeping establishment, beekeeping types, beekeeping materials, beekeeping systems, bee reserves and calendar), bee products and services (bee products processing, bee products quality, bee services and hive products) and challenges to bee biodiversity (biological

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threats, environmental and anthropogenic threats, pathological threats and colony collapse disorder).

This documentation is organized as follows: Section 2 contains PBO ontology metadata; Section 3 gives information about reused external thesauri; 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 Protégé[2] 5.6.5, which supports OWL 2 (Web Ontology Language), Resource Description Framework (RDF) and Description Logic (DL). The SPARQL[3] 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.

3 Reused external thesauri

The PBO ontology reused the concepts and relations from AGROVOC[4] Multilingual Thesaurus and the General Multilingual Environmental Thesaurus (GEMET[5]), for example "c_3652" for "Honey_" 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 Beekeeper_ and Apiculture_ that they have external link to AGROVOC thesaurus.

[1] `https://creativecommons.org/licenses/by-sa/4.0/`
[2] `https://protege.stanford.edu/software.php#desktop-protege`
[3] `https://sparql.dev/article/SPARQL_and_ontology_development.html`
[4] `https://agrovoc.fao.org/browse/agrovoc/en/page/c_529`
[5] `https://www.eionet.europa.eu/gemet/en/themes/`

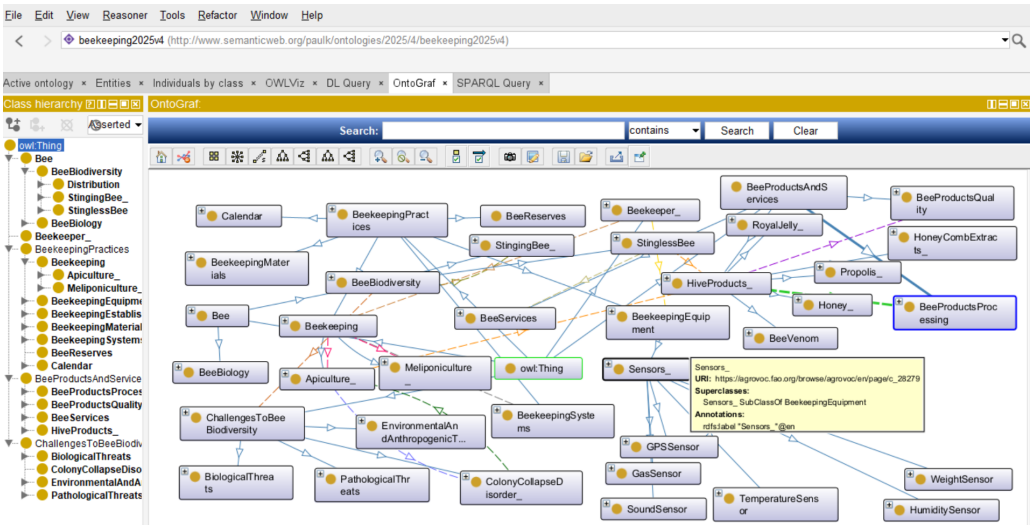


Figure 1: Class hierarchy and visualization of the PBO ontology using the built-in OntoGraf tool in the Protégé

4 PBO ontology structure

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.

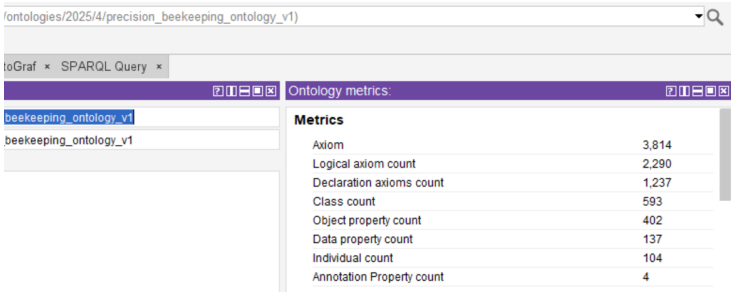


Figure 2: Metrics of the PBO ontology from the Protégé

- PBO ontology has 3814 axioms, whereby 2290 axioms are logical and 1237 axioms are declarative.
- PBO ontology has 593 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 402, which defines the relationship between classes. For example, the object property that links the "Beekeeper_" class and the "Beekeeping" class is shown in Figure 3 "performs" which was reused from AGROVOC. The reused object properties from AGROVOC can be determined by the class (subject or object) that has underscore (_). Some of object properties defined are seen in Figure 4.

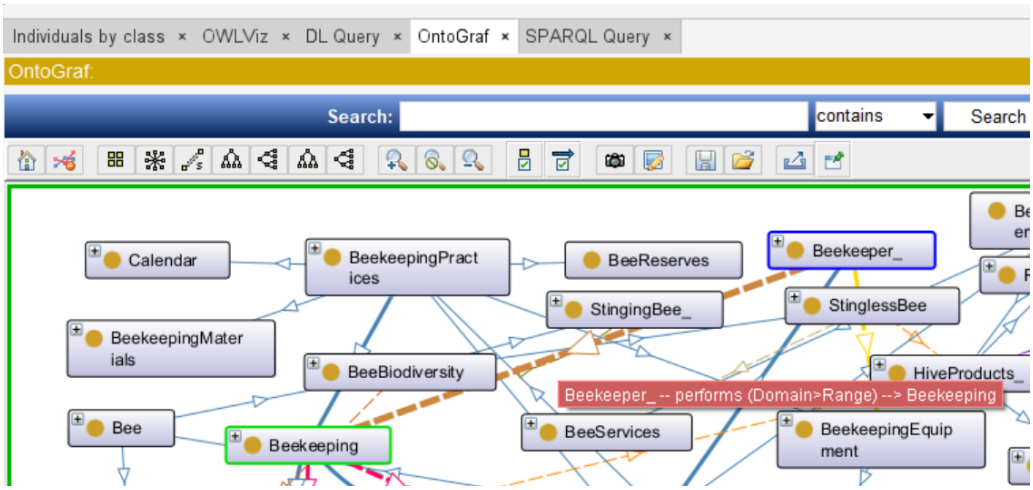


Figure 3: Visualization of the performs object property between the Beekeeper class and the Beekeeping class using the built-in OntoGraf tool in the Protégé

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

- The data property count is 137 in the PBO ontology and some of them are seen in Figure 5.

- The individual count is 104 in PBO ontology, which contains domain-

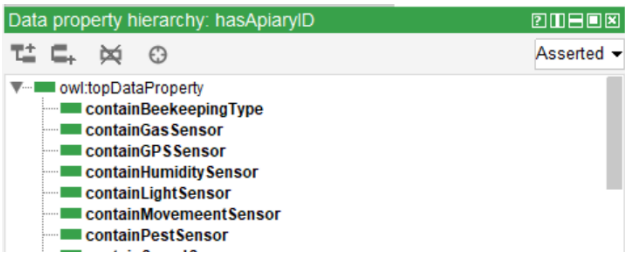


Figure 5: Snippet of Data Property Hierarchy in Protégé for PBO Ontology

specific knowledge instances rather than field data in precision beekeeping and some are seen in Figure 6.

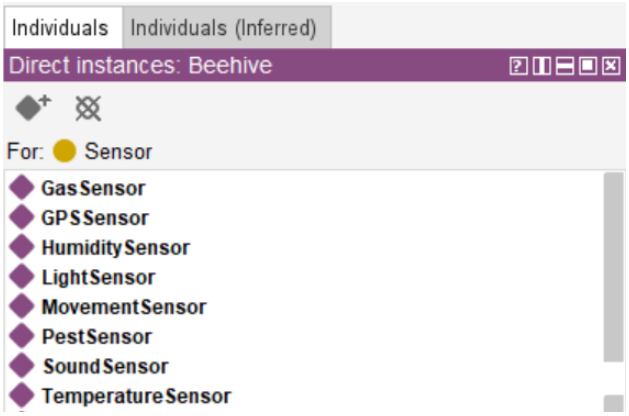


Figure 6: Snippet of individuals (instances) in Protégé for PBO Ontology

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 existential and cardinality constraints in Figure 7 show that the "SingleQueenColony" class can contain exactly one "MatedQueen" specified under the property "containsMatedQueen".

We also specified the domain and range restrictions on the object properties for example makeUseOf object property with the domain BeeFeeding class and the ranges Pollen, Nectar, BeePlants, RoyalJelly and Honeydew classes.

In specifying restrictions on data properties, we specified value datatypes, domain and range restrictions such as containBeekeepingType data property link between Beekeeping class as domain and xsd:string as range.

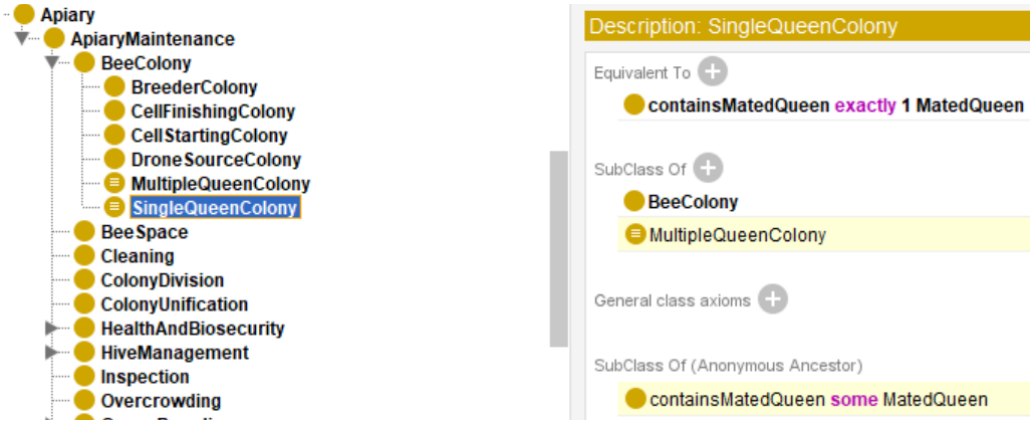


Figure 7: Snippet of Object Property restrictions in Protégé for PBO Ontology

6 SPARQL queries and results of PBO ontology

The PBO ontology was evaluated based on the pre-defined competence questions (CQs) that we used to set the domain coverage and scope of this ontology. 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 10 CQs. Figure 9 shows the total number of triples uploaded 3823, from the PBO ontology, from which CQ1 (What are the products produced by the honeybees?) is illustrated in Figure 10.

Figure 11 illustrates instances of the results for CQ1 for corresponding query in Figure 10 of which some instances have links to AGROVOC, while some not available in AGROVOC or GEMET. The other CQs 2 to 10 for SPARQL queries and results are available in Appendices A to R.

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 real-world data from hives connected with sensors in the apiary.

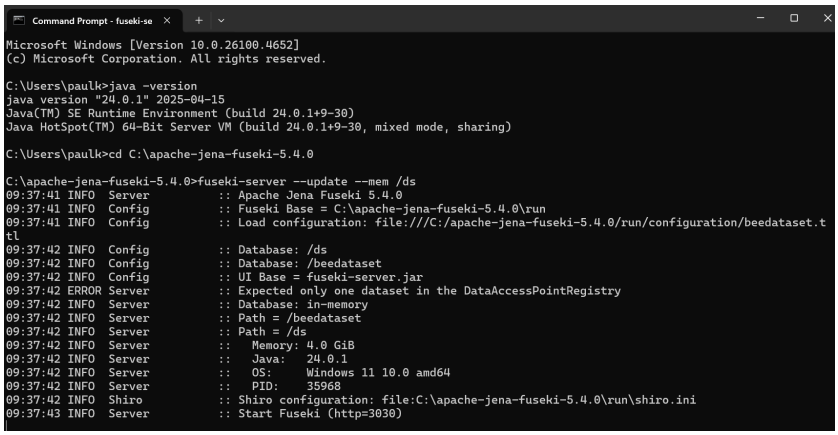


Figure 8: Setting the Apache Jena Fuseki Server for Ontology Evaluation

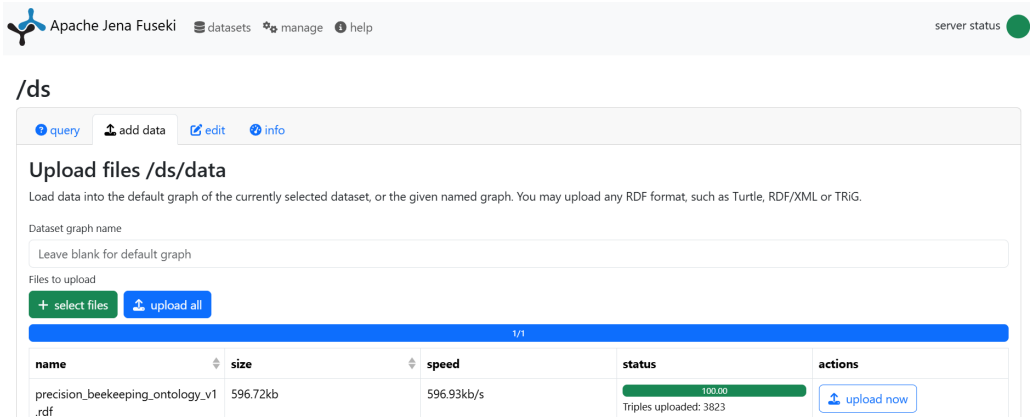


Figure 9: Triples uploaded in Apache Jena Fuseki server for running SPARQL queries

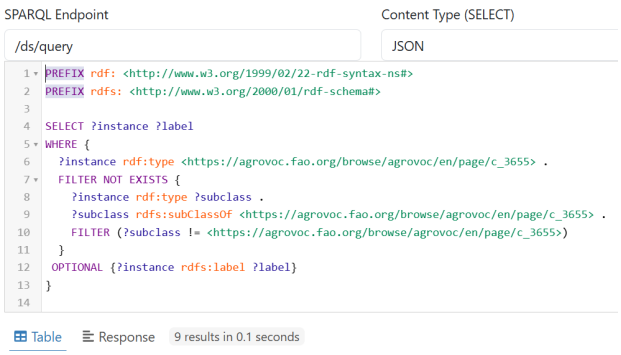


Figure 10: SPARQL query for Competence Question 1 (CQ1) in Jena Fuseki Server for Ontology Evaluation

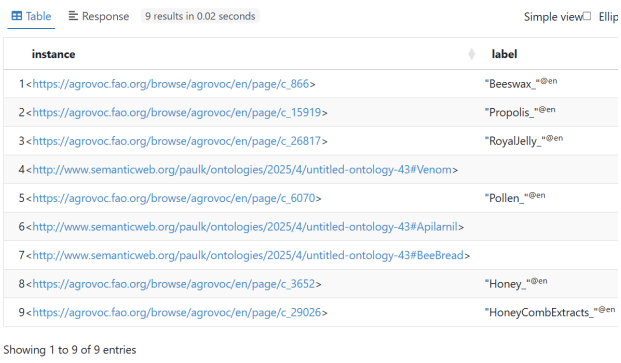


Table Response 9 results in 0.02 seconds Simple view Ellip

	instance	label
1	<https://agrovoc.fao.org/browse/agrovoc/en/page/c_866>	"Beeswax_"@en
2	<https://agrovoc.fao.org/browse/agrovoc/en/page/c_15919>	"Propolis_"@en
3	<https://agrovoc.fao.org/browse/agrovoc/en/page/c_26817>	"RoyalJelly_"@en
4	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43#Venom>	
5	<https://agrovoc.fao.org/browse/agrovoc/en/page/c_6070>	"Pollen_"@en
6	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43#Apilarnil>	
7	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43#BeeBread>	
8	<https://agrovoc.fao.org/browse/agrovoc/en/page/c_3652>	"Honey_"@en
9	<https://agrovoc.fao.org/browse/agrovoc/en/page/c_29026>	"HoneyCombExtracts_"@en

Showing 1 to 9 of 9 entries

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

Appendices

A : CQ 2: What are the subspecies of the stinging bees, Genus Apis (True honeybees) and others?

SPARQL Endpoint

/ds/query

Content Type (SELECT)

JSON

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT ?instance ?label
WHERE {
  ?instance rdf:type <https://agrovoc.fao.org/browse/agrovoc/en/page/c_533> .
  FILTER NOT EXISTS {
    ?instance rdf:type ?subclass .
    ?subclass rdfs:subClassOf <https://agrovoc.fao.org/browse/agrovoc/en/page/c_533> .
    FILTER (?subclass != <https://agrovoc.fao.org/browse/agrovoc/en/page/c_533>)
  }
 OPTIONAL {?instance rdfs:label ?label}
}
```

Table Response 10 results in 0.032 seconds Simple view

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

B : SPARQL query results for CQ 2

	instance	label
1	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/ApisNigrocincta>	
2	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/ApisNuluensis>	
3	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/ApisDorsata>	
4	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/ApisKoschevnikovi>	
5	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/BombusTerrestris>	
6	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/ApisLaboriosa>	
7	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/ApisCerana>	
8	<https://agrovoc.fao.org/browse/agrovoc/en/page/c_534>	"ApisMellifera_"@en
9	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/ApisFlorea>	
10	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/ApisAndreniformis>	

Showing 1 to 10 of 10 entries << < 1 > >>

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

C : CQ 3: What are the types of equipment and tools used in precision beekeeping?

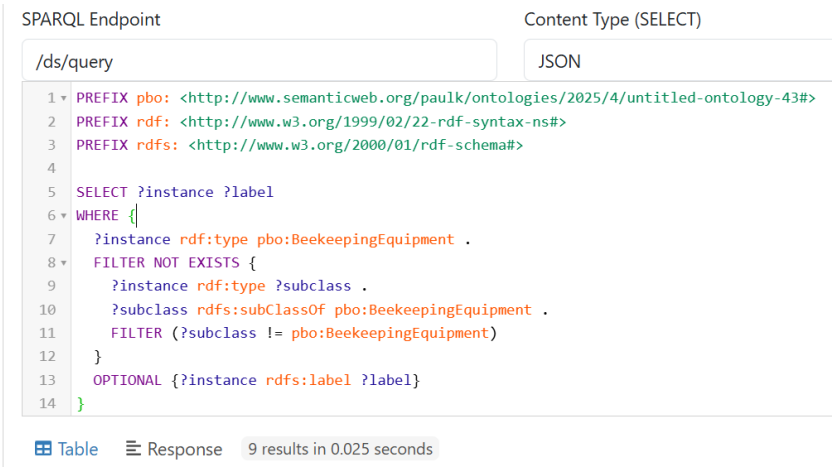


Figure 14: SPARQL query for CQ 3 in Apache Jena Fuseki Server

D : SPARQL query results for CQ 3

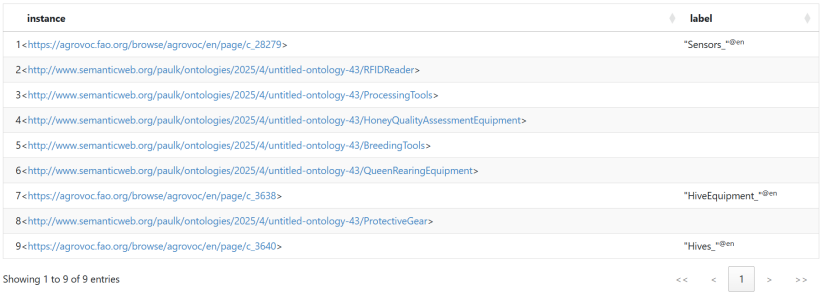


Figure 15: SPARQL query results for CQ 3 in Apache Jena Fuseki Server

E : CQ 4: What are the different types of sensors needed in precision beekeeping?

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://agrovoc.fao.org/browse/agrovoc/en/page/c_28279> .
7    FILTER NOT EXISTS {
8      ?instance rdf:type ?subclass .
9      ?subclass rdfs:subClassOf <https://agrovoc.fao.org/browse/agrovoc/en/page/c_28279> .
10     FILTER (?subclass != <https://agrovoc.fao.org/browse/agrovoc/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

	instance
1	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/GPSSensor>
2	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/TemperatureSensor>
3	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/PestSensor>
4	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/HumiditySensor>
5	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/VentilationSensor>
6	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/WeightSensor>
7	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/LightSensor>
8	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/SoundSensor>
9	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/GasSensor>
10	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/MovementSensor>

Showing 1 to 10 of 10 entries

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

G : CQ 5: What are the beekeeping types?

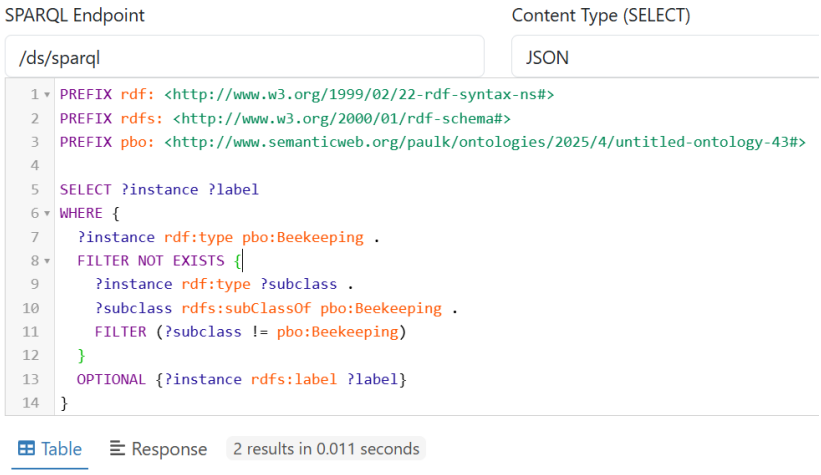


Figure 18: SPARQL query for CQ 5 in Apache Jena Fuseki Server

H : SPARQL query results for CQ 5

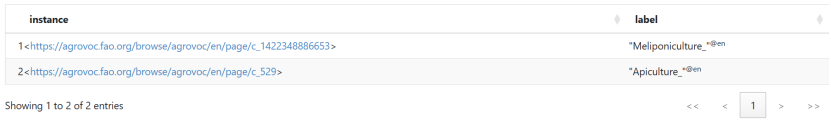


Figure 19: SPARQL query results for CQ 5 in Apache Jena Fuseki Server

I : CQ 6: What are the types of modern beehives?

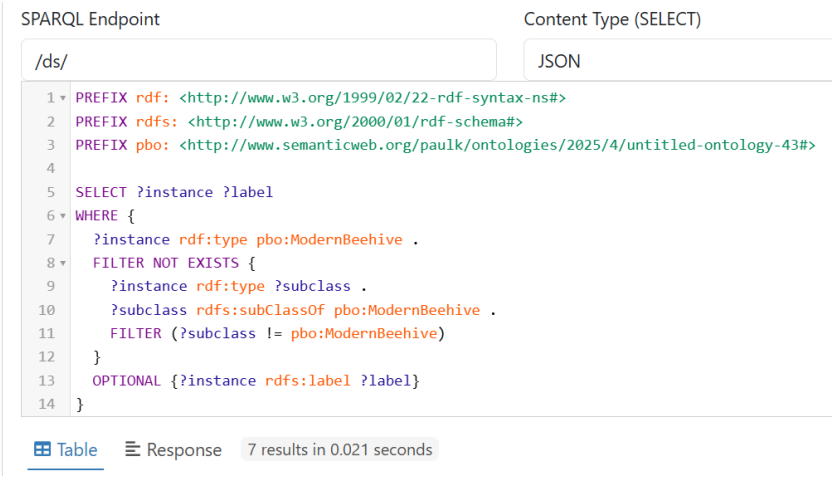


Figure 20: SPARQL query for CQ 6 in Apache Jena Fuseki Server

J : SPARQL query results for CQ 6

instance
1<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/FlowBeehive>
2<http://www.semanticweb.org/paulk/ontologies/2025/4/precision_beekeeping_ontology_v1#DadanHive>
3<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/FramesBeehive>
4<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/TopBarBeehive>
5<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/ObservationalBeehive>
6<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/LangstrothBeehive>
7<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/SmartHives>

Showing 1 to 7 of 7 entries

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

K : CQ 7: What are the types of beekeeping systems?

SPARQL Endpoint

/ds/

Content Type (SELECT)

JSON

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX pbo: <http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43#>

SELECT ?instance ?label
WHERE {
  ?instance rdf:type pbo:BeekeepingSystems .
  FILTER NOT EXISTS {
    ?instance rdf:type ?subclass .
    ?subclass rdfs:subClassOf pbo:BeekeepingSystems .
    FILTER (?subclass != pbo:BeekeepingSystems)
  }
  OPTIONAL {?instance rdfs:label ?label}
}
```

Table Response 7 results in 0.034 seconds

Figure 22: SPARQL query for CQ 7 in Apache Jena Fuseki Server

L : SPARQL query results for CQ 7

instance
1<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/HoneyHunting>
2<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/UrbanBeekeeping>
3<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/MigratoryBeekeeping>
4<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/WildBeekeeping>
5<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/RuralBeekeeping>
6<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/TraditionalBeekeeping>
7<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/ModernBeekeeping>

Showing 1 to 7 of 7 entries

Figure 23: SPARQL query results for CQ 7 in Apache Jena Fuseki Server

M : CQ 8: What are the challenges/threats to Bee Biodiversity?

SPARQL Endpoint: /ds/sparql

Content Type (SELECT): JSON

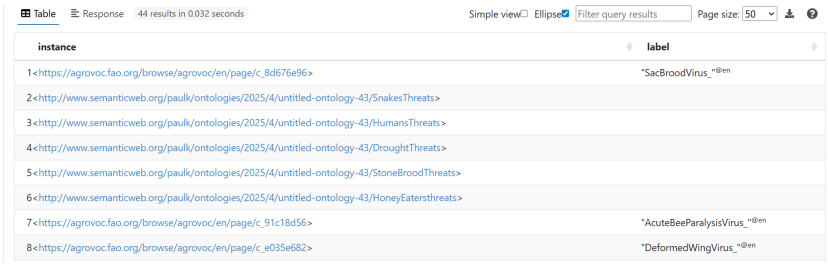
```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX pbo: <http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43#>

SELECT ?instance ?label
WHERE {
  ?instance rdf:type pbo:ChallengesToBeeBiodiversity .
  FILTER NOT EXISTS {
    ?instance rdf:type ?subclass .
    ?subclass rdfs:subClassOf pbo:ChallengesToBeeBiodiversity .
    FILTER (?subclass != pbo:ChallengesToBeeBiodiversity)
  }
  OPTIONAL {?instance rdfs:label ?label}
}
```

Table | Response | 44 results in 0.032 seconds

Figure 24: SPARQL query for CQ 8 in Apache Jena Fuseki Server

N : SPARQL query results for CQ 8



	instance	label
1	<https://agrovoc.fao.org/browse/agrovoc/en/page/c_8d676e96>	"SacBroodVirus_"@en
2	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/SnakesThreats>	
3	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/HumansThreats>	
4	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/DroughtThreats>	
5	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/StoneBroodThreats>	
6	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/HoneyEatersthreats>	
7	<https://agrovoc.fao.org/browse/agrovoc/en/page/c_91c18d56>	"AcuteBeeParalysisVirus_"@en
8	<https://agrovoc.fao.org/browse/agrovoc/en/page/c_e035e682>	"DeformedWingVirus_"@en

Figure 25: SPARQL query results (8 out of 44) for CQ 8 in Apache Jena Fuseki Server

O : CQ 9: What are the bee human-centric services?

SPARQL Endpoint: /ds/sparql

Content Type (SELECT): JSON

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX pbo: <http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43#>

SELECT ?instance ?label
WHERE {
  ?instance rdf:type pbo:BeeHumanCentricServices .
  FILTER NOT EXISTS {
    ?instance rdf:type ?subclass .
    ?subclass rdfs:subClassOf pbo:BeeHumanCentricServices .
    FILTER (?subclass != pbo:BeeHumanCentricServices)
  }
  OPTIONAL {?instance rdfs:label ?label}
}
```

Table | Response | 3 results in 0.035 seconds

Figure 26: SPARQL query for CQ 9 in Apache Jena Fuseki Server

P : SPARQL query results for CQ 9

	instance
1	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/Apitherapy>
2	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/Apitourism>
3	<http://www.semanticweb.org/paulk/ontologies/2025/4/untitled-ontology-43/Apibusiness>

Showing 1 to 3 of 3 entries

Figure 27: SPARQL query results for CQ 9 in Apache Jena Fuseki Server

Q : CQ 10: What are the bee ecosystem services?

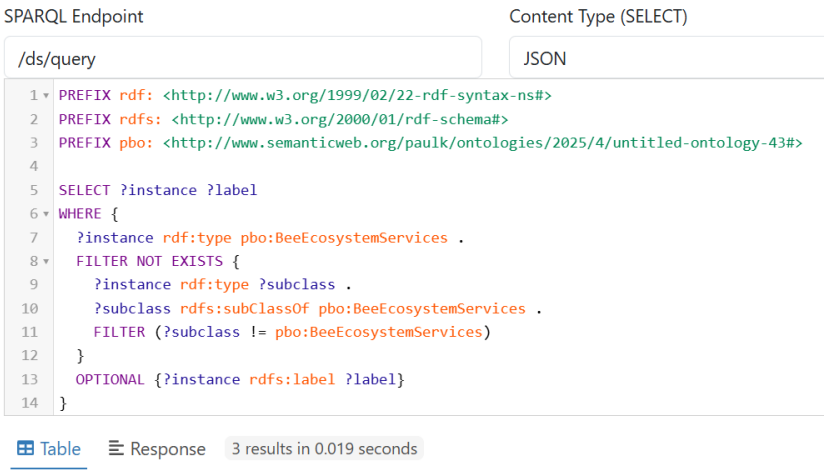


Figure 28: SPARQL query for CQ 10 in Apache Jena Fuseki Server

R : SPARQL query results for CQ 10

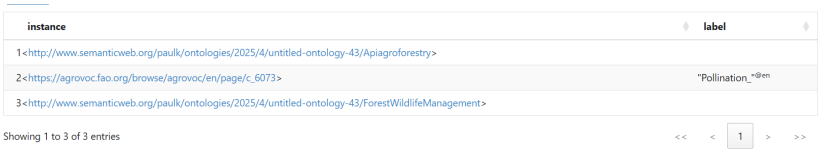


Figure 29: SPARQL query results for CQ 10 in Apache Jena Fuseki Server