BirdWatch—Supporting Citizen Scientists for Better Linked Data Quality for Biodiversity Management

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Abstract. Observational data about species of public interest, such as birds and butterflies, is often created and collected by volunteered citizen scientists, and used by professionals for managing biodiversity. The education and skills of the citizens participating in the work varies a lot, and the process of making observations is typically not systematic but rather ad hoc. As a result, the quality of the observational data in repositories, such as the Global Biodiversity Information Facility GBIF Data Portal, is often not good, hampering its utilization severely. This paper presents an approach for enhancing data quality in a citizen science setting, and presents a mobile tool BirdWatch for citizen observers, mitigating difficulties in producing high quality Linked Data for biodiversity management.

1 Introduction

Biodiversity [1, 6] management (BM) is based on observations of the nature. Special concerns of the field include changes in our environment that lead to undesired changes in the populations of organisms, such as the spread of harmful invasive alien species or extinction of endangered species. Based on observations and their time series, such changes can be identified in time and necessary measures of nature conservation be initiated.

In many areas of biology, much of the observational data is based on citizen science: the data comes from masses of amateurs observing plants, animals, and other organisms of their interest. In this way it is possible to gather lots of useful data for minimal costs. Such data is systematically collected in databases in many countries and also aggregated by organizations such as GBIF[1] on an international level. Today, the GBIF Data Portal includes nearly 400 million observations in over 10,000 datasets, hosted in a network of servers of ca. 420 nature organizations around the world.

Observing the nature and reporting findings is getting more and more popular, and many of the GBIF datasets are based on the observations of volunteered

[1] http://www.gbif.org/

amateurs. The most active domain of biology here is ornithology. In Finland, for example, there are over 10,000 active birdwatchers[2] reporting their observations to databases, about 0.2% of the whole population. The amateurs are equipped with varying knowledge and skills, and the process of making observations is typically rather self-organizing and ad hoc than systematic. As a result, the *quality* of observations varies a lot in different ways:

1. **Misinterpretations** There are lots of misinterpretations of species in the data, e.g., an arctic tern reported as a common tern.
2. **Uncertainty** The observations and data may be uncertain, which may be difficult to represent in a harmonized way.
3. **Trust** Data from an experienced ornithologist should be more reliable than data from a beginner, but this cannot usually be represented and evaluated.
4. **Incompleteness** The data may be incomplete. For example, values may be missing from records, or data in one dataset lacks certain metadata element values or describe them at a different level of granularity.
5. **Statistical biases** The data is statistically concentrated on certain areas, times, and on certain species of interest to the public. Especially big and beautiful species are frequently reported, as well as early or late observations of migratory species.
6. **Machine Interpretability** Observations are represented in different syntactic ways and often using natural language phrases that may be difficult to interpret by the machine.
7. **Interoperability** Metadata about the observations is represented using different models, and different species lists [12] may be in use in different countries.

This paper presents a solution and an online tool that can be used for supporting citizen scientists in producing better quality observational data for biodiversity management. We argue that at least the following requirements are needed for such a system:

1. **Make use of statistical data** of related observations based on the current spatio-temporal context. If someone is trying to report an observation that is very different from the others made at the same place and time before (e.g., a swallow in winter time in Finland), there is a particularly high risk of misinterpretation. Supporting or refuting the observational data of other observers should be provided at the time and place where a new observation is being considered and reported.
2. **Provide identification support based on species characteristics**. Information about the characteristics of the proposed species and related species that look or sound similar is crucial when identifying species.
3. **Shorten the learning curve and boost motivation**. It may take several years to become a reliable nature observer, say an ornithologist. The system should therefore speed up this process by 1) shortening training time and 2)

[2] http://www.birdlife.fi/

also keeping the observer motivated in continuing in her hobby. Providing statistical [4] and ontological data about the species not only helps the end-user in making the identification right, but also teaches her, so that in the future higher quality observations are possible with less help.

4. **Help in creating interoperable data**. Creating observation records is tedious manual work that also distracts the observer from the main task of making observations. The system should therefore help the end-user in creating the observation data record. The data should also be represented in a machine readable, unambiguous, and interoperable way so that its can be processed later correctly and aggregated with other observations.

This paper presents an approach and an online system, "BirdWatch—Mobile Semantic Service for Birding" addressing these issues. As a methodological and technological basis, Semantic Web[3] and Linked Data [3] are used. A major technical novelty of the BirdWatch system is its ability to use and mix both statistical data, based on observation databases, and ontological a priori knowledge about the application domain, in this case birds and their characteristics, places, and times. Based on such a mixture of data, the system is able to support or critique suspicious observations in a spatiotemporal context, suggest possible alternative identifications, provide identification support based on bird characteristics, provide species-wise links to other web services (e.g., to identification documents and field guides, to bird song registries[4], and to online species identification systems), and in this way to teach the end-user in order to shorten her learning curve and to motivate her learning more. In addition, the system helps the observer in filling in data records for a legacy observation service, based on its knowledge about the context of the observation. BirdWatch is available online[5] as web application for mobile and desktop users. Additional plug-ins or application software are not needed.

In the following, the datasets, metadata model, and ontologies underlying the service are first explained. After this, an example use case of using the system is presented illustrating the functionalities of the system, and our prototype implementation is discussed shortly. The system is in trial use on the web. In conclusion, the contributions of the paper are summarized, related work is pointed out, evaluation strategies for the system are discussed, and directions for further research are outlined.

2 Data, Metadata, and Ontologies

This section explains the data, metadata, and ontologies used in BirdWatch.

[3] http://www.w3.org/standards/semanticweb/
[4] See, e.g., http://xeno-canto.org/
[5] See http://demo.seco.tkk.fi/birdwatch/. The service contains observation data only within Finland.

2.1 Observational Data

The data underlying the prototype comes from the GBIF Data Portal[6], hosting over 396,000,000 observations gathered all over the world. Our focus is on the Tiira dataset of Birds, based on the Finnish Tiira service[7] created by BirdLife and some 30 national birdwatching associations in Finland. The Tiira dataset contains 7,800,000 records. For demonstrational purposes, we selected recent data during 2007–2011 (5 years) and picked up 250,000 observations per year randomly, totaling in 1.25 million data records.

Table 1. Metadata Element Set for Observations

Element	**Meaning**	**Identifier**	**Card.**	**Range type**	**Value**
Species	Observed species	hh:scientific_name	1	taxmeon:TaxonInChecklist	URI
Place	WGS84 latitude	geo:lat	1	Literal	string
	WGS84 longitude	geo:long	1	Literal	string
Date	observation date	hh:date_collected	1	xsd:date	string
	Day of the year	owl-time:dayOfYear	1	xsd:nonNegativeInteger	1–366
Additions	Species in NatureGate	hh:general	0..1	Boolean	true/false
	Misindetifications	envirofi:hasCommonMisidentification	0..n	taxmeon:taxonInChecklist	URI

2.2 Metadata Model

The metadata was available in CSV format and was transformed into RDF in order to create a "5-star" linked data publication of it [3]. As a platform, the SAHA-HAKO system [5] was used and developed further[8] (e.g., the system is now directly based on a SPARQL endpoint for modularity). SAHA-HAKO creates automatically an editing environment for data with data validation functions, a faceted search engine based on the data, and a SPARQL endpoint for utilizing the data in a flexible way in applications. The RDF-based metadata model used in BirdWatch is shown in Table 1, using the namespaces below:

```
geo:       <http://www.w3.org/2003/01/geo/wgs84_pos#>
hh:        <http://www.hatikka.fi/havainnot/>
taxmeon:   <http://www.yso.fi/onto/taxmeon/>
owl-time: <http://www.w3.org/TR/owl-time/>
envirofi: <http://www.yso.fi/onto/envirofi/>
```

Here `geo` refers to the W3C Geospatial Vocabulary[9], `hh` to the observation database Hatikka of the Finnish Museum of Natural History[10] (FMNH), `taxmeon` to the taxonomic metaontology model of [12], `owl-time` to the Time Ontology in OWL[11], and `envirofi` to the EU FP7 project ENVIROFI[12]. Each observation

[6] http://data.gbif.org/welcome.htm
[7] http://www.tiira.fi/
[8] The source code is available at http://code.google.com/p/saha/
[9] http://www.w3.org/2005/Incubator/geo/XGR-geo-20071023/
[10] http://www.luomus.fi/english/
[11] http://www.w3.org/TR/owl-time/
[12] http://www.envirofi.eu/

in the GBIF data is associated to a geolocation square of 10 km x 10 km; the data publisher has not been willing to disclose the exact coordinates of observations in order to, e.g., protect endangered species. Unfortunately, more accurate geodata was not available in GBIF for common species either.

2.3 Ontologies

The basis of the system is the Birds of the World Ontology AVIO [13] we have developed. This ontology is based on the spreadsheet data available from BirdLife and FMNH, listing all birds of the world comprehensively, including scientific, English, and newest recommended Finnish names[13] [14]. The taxonomy was completed by adding higher level taxa (27 orders, 1 class and 1 kingdom) into the system obtained from the taxonomic database[14] of FMNH. This data was transformed into an ontology based on the TaxMeOn metaontology model [12] and is available as open data and as a public service in the ONKI Ontology Service[15] [11, 15]. The final AVIO ontology contains 9,740 species, 1,227 genera, and 194 families, defining the class of birds. Also a SKOS version of the ontology was created, where AVIO was extended with a corresponding vernacular namelist for the Swedish names of birds[16].

When porting AVIO to BirdWatch, some modifications and extensions to the AVIO ontology were made:

1. Tiira data uses in some cases older names for some species. These were added into the ontology manually as alternative names.
2. The ontology was enriched with envirofi:hasCommonMisidentification properties identifying similar looking species that are easily mixed. This work was based on an authoritative field guide [9] and was done by an experienced amateur ornithologist.
3. A mapping to bird species presented in more detail in the NatureGate service[17] was created. This facilitates linking BirdWatch and NatureGate services species-wise.
4. An extension to AVIO specifying characteristics of bird species was created, based on the characteristics system used in NatureGate. This system classifies birds, in terms of four major facet categories: 1) Date and location (nesting habitat), 2) Coloring and markings, 3) Shape and size, and 4) Behavior. These categories are further classified into hierarchies of subcategories. For instance, Shape and size contains subcategories for Size, Wings, Legs, Beak, Chest, Neck, and Tail on the next level. Finally, each species can be characterized by a set of values taken from the most specific categories. The identification of species can be performed as faceted search (cf., e.g., [10,

[13] http://www.birdlife.fi/lintuharrastus/nimisto/Maailman-lintujen-suomenkieliset-nimet–systemaattinen-osa.txt
[14] http://taxon.luomus.fi/
[15] http://onki.fi/en/browser/overview/linnut
[16] http://www.luomus.fi/julkaisut/muut/lintunimet/lintunimet-ruotsinkieliset.txt
[17] http://www.naturegate.fi/

2]) using the four major classification schemes as facets. There are currently 141 categories in the four hierarchical facets, such as “Short and sharp beak” and “Main color brown”. In our prototype, the facets used in NatureGate were used as they are for interoperability.
5. Since BirdWatch is used for observations in Finland, AVIO ontology was pruned for this application case by removing, e.g., tropical and Australian species from it.

The bird characteristics system can be used for not only search (as in NatureGate), but also for identifying automatically potential misinterpretations between species, and point out how the species are different. For example, the characteristics of the arctic tern and common tern are quite similar with small differences regarding, e.g., beak coloring (common tern typically has some black there). A challenge in using characteristics of birds for identification is that they depend on the age of the individual, visual lighting conditions, season, and other changing factors. However, pointing out possible characteristics that may identify and differentiate bird species is the method used in guide books and is the basis for learning to identify species.

In the current version of our prototype, the bird characteristics extension to AVIO has not yet been used for automatic misconception identification. Instead, the common misconceptions links added into the AVIO ontology are used. An interesting further research question is how well misconceptions could be derived automatically based on the faceted characteristics system by, e.g., supervised learning, and whether the system after this could be used for identifying additional useful misconceptions.

3 Use Case Example

This section illustrates BirdWatch functionalities by a use case.

Assume that Olly Observer sees a bird that looks like an arctic tern near Helsinki on May 1. He would like to report about this to the Tiira system because in his mind this could be a rare observation worth reporting at the given time.

Olly opens BirdWatch page on the web with his mobile phone, and the system asks permission for positioning. He accepts this, and system pre-fills the observation form with coordinates and the current date (cf. Fig. 1). Olly then starts writing in data for the *Species* field “a..r..c..”, and the system quickly autocompletes this into the full name “arctic tern”. After this there are two options to proceed: 1) Pushing the *Check* button would retrieve supporting and critiquing information for the hypothetical observation. 2) Send button would send the data to the Tiira.fi service without providing such information—in this case Olly should be confident about the identification. Olly decides to push *Check* because he is not quite sure about the bird species, and the system provides him with the following information for consideration under the *Check* button, cf. Fig. 1:

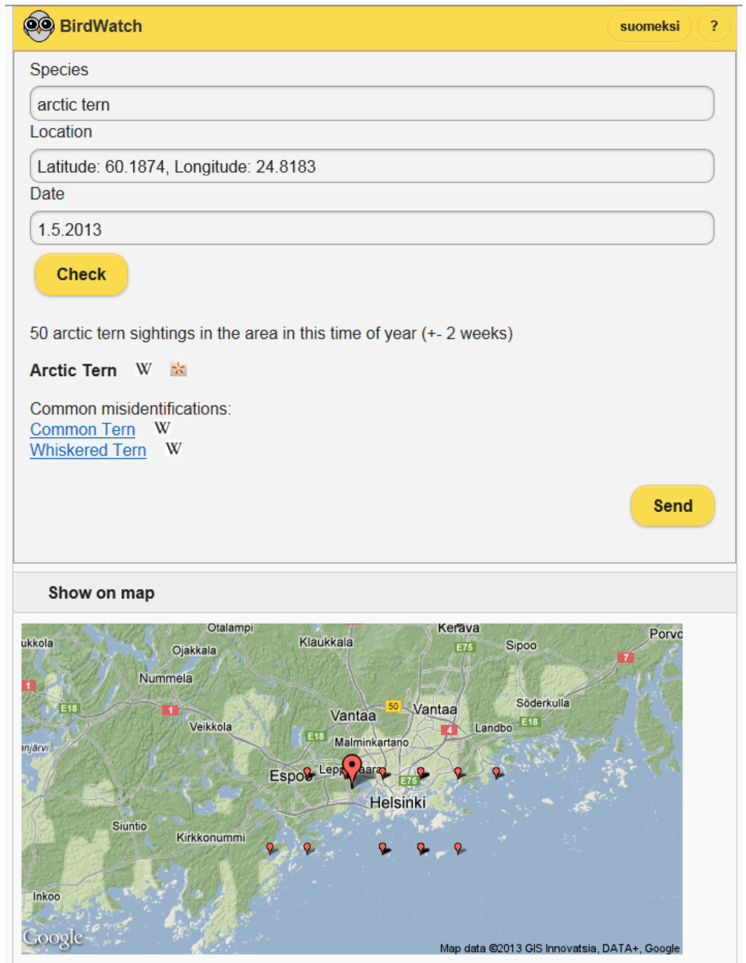

Fig. 1. Screenshot with a map showing the current position and related observations.

1. The number (50) of similar observations in the given area and within a time interval of two weeks before or ahead is presented. A low number can be considered a warning of possible misinterpretation. In this case, however, the number 50 suggests that the observation is not particularly rare and definitely possible.
2. Links to recommended identification services on the web for the arctic tern are provided, here links to the arctic tern pages of Wikipedia and NatureGate (indicated by special button symbols).
3. Links to commonly misinterpreted species of the arctic tern are provided, in this case the common tern and the whiskered tern. By following these links, Olly can change the proposed observation and get new statistics for

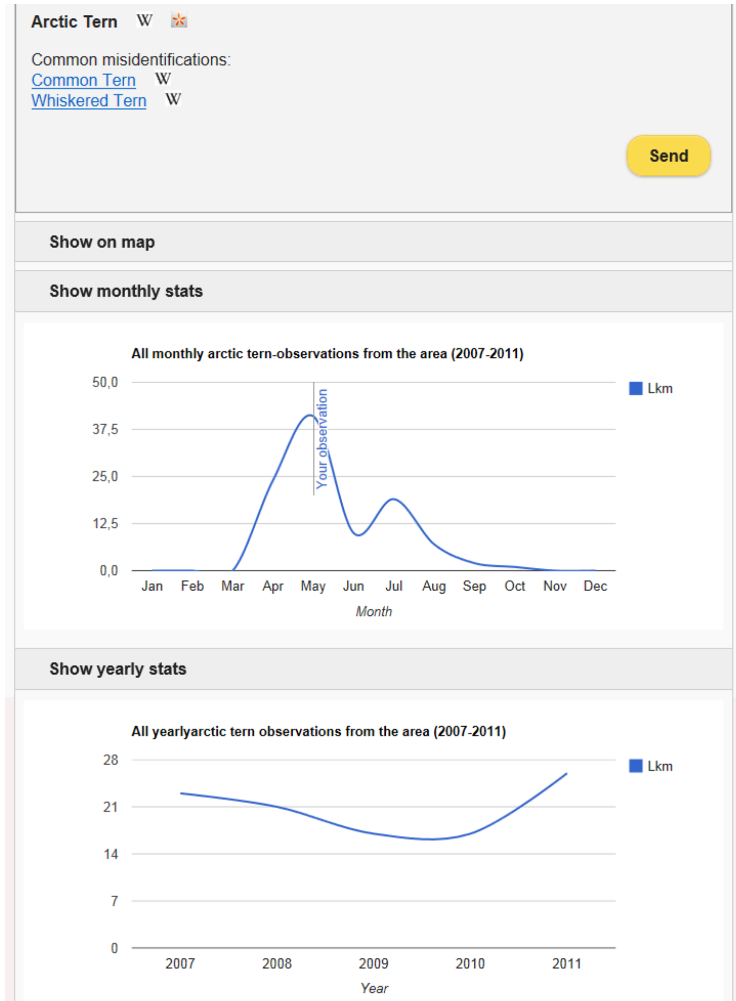

Fig. 2. Screenshot with statistical info related to the observations.

these species and other information. In this case, the statistics would tell that there are no observations made in this place and time about whiskered terns, so this option would be unlikely (although possible). However, there are 192 observations of the common tern, raising the question whether Olly actually saw a common tern.

4. After each listed possible misconception there are links to further information services on the web. In our prototype, links to species pages in Wikipedia and NatureGate are provided, but the list can be extended to other sources, too, such as online bird song registries, based on linked data. Olly can find

out in this way characteristics differentiating the common and arctic terns, if he does not recall them otherwise.

5. Arctic tern observations on the map are shown, centered around the current location. The idea here is that observations nearby may support the current identification hypothesis or be against it.
6. A monthly statistics of arctic tern observations at the spot in the given time frame is shown (cf. Fig. 2). This visualization complements information about possible misconceptions in time: it may be the case that even if similar observations were rare at this point in time, the situation could change radically due to, e.g., migration soon. In this case, the situation is indeed very dynamic—the number of observations increases quickly during April—but on May 1 the peak has already been reached.
7. Also a yearly statistics of all arctic tern observations in the area is shown. This is an interesting piece on knowledge from a biodiversity point of view and could be of interest to Olly. A raising and high number of similar observations indicates that the species is generally not rare and provides some support that the hypothesized observation is feasible.

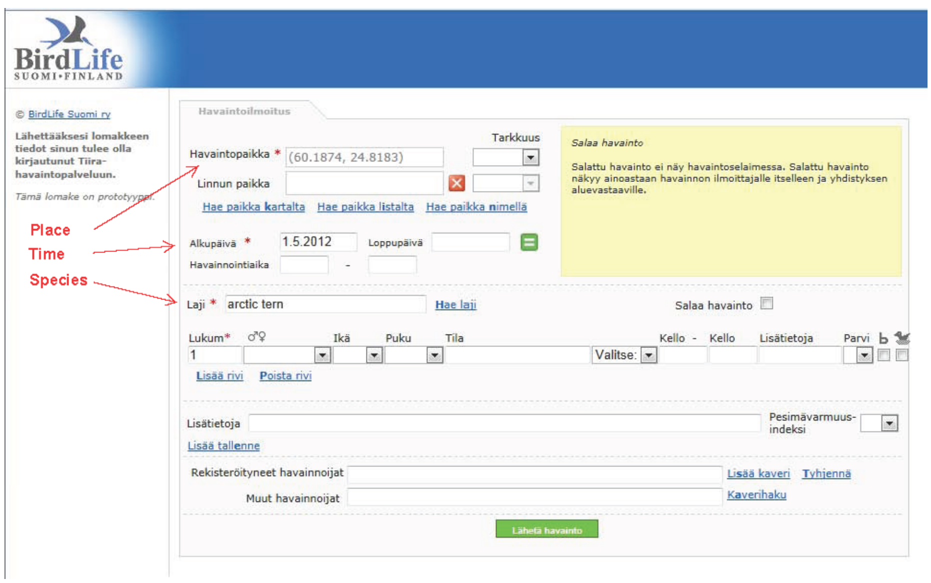

Fig. 3. Pre-filled observation form for the Tiira service.

Given the information listed above, Olly thinks that the observation hypothesis arctic tern seems to be correct and pushes the *Send* button to submit the observation into the Tiira system. The system then fills in partly the legacy Tiira observation submission form[18] as depicted in Fig. 3, including, e.g., fields for the species, time, and location. In this way the time needed for filling up the data is shortened, which saves time for the actual observation work. Obviously, a less time consuming reporting system also motivates end-users to actually submit their observations. In the prototype, we use the Tiira legacy reporting form as it is, designed for desktop devices. Designing a better interface for mobile devices remains a topic for further development.

In short, the system provides statistical knowledge in context for evaluating the feasibility of the proposed observation, ontology-based information about possible misinterpretations, links to additional web services that may help in the identification and for learning more about the species, and finally speeds up reporting by pre-filling observational reports.

Some fields of the data record can be filled automatically based on the context of observation (e.g., place and time), for others, such as species reference, ontology services [11, 7] can be used for finding and fetching the right URIs.

4 Implementation and Visualization

The BirdWatch prototype is an HTML5 Mobile application that is implemented using JQuery Mobile[19]. The autosuggestion of species, recommendation links, and visualizations are created and queried directly from the underlying linked data SPARQL endpoint using Ajax requests. The application uses W3C Geolocation API[20] for detecting the location of the user. The user can also position the observation by inputting the name of the location or address that is then processed with the Google Maps API[21]. Once the user has given the input about the species, and the location of the observation and time are known (also time can be changed manually), a SPARQL query is send to the observation triplestore and the observations of the given area and time are analyzed and visualized.

The fuzzy locations (+-10km) of the observation data are plotted on a map, and details about the observations in the area are processed from the JSON serialization of the SPARQL response using the same method as in sgvizler [8]. The query results are transformed into a format used by the Google chart library[22], and represented as a graph visualizing the fluctuations of observation data on a monthly and yearly basis.

5 Discussion and Evaluation

Species distribution maps for different times (e.g., for nesting time and overwintering) are widely used for species identification, and maps are available in field

[18] http://www.tiira.fi/, the web form is available in Finnish and Swedish
[19] http://jquerymobile.com/
[20] http://www.w3.org/TR/geolocation-API/
[21] https://developers.google.com/maps/
[22] https://developers.google.com/chart/

books, such as [9]. Online systems, such as eBird[23] used by, e.g., the Audubon Society, provide online visualizations of observations, such as range and point maps and yearly bar charts. Different metrics of observations can be graphed along a timeline and statistics of one species contrasted with others. Data mining tools can be applied to observational databases in order to analyze and discover phenomena that take place in the nature [4]. There are charactetistics-based mobile bird identification systems online, such as WildLab-Bird[24], iNaturalist[25], Project Noah[26], and NatureGate[27], aiming at teaching birdwatching to citizens and at the same time collecting observations.

BirdWatch makes use of GBIF data and its metadata model[28] (based on Ecological Metadata Language EML) that is transformed directly into RDF. Other metadata formats and vocabularies used for describing observational data include, e.g., Darwin Core[29] and OBOE OWL[30]. In our case, there was no need for complex modeling since the underlying data available was simple GBIF data. As for species ontologies, related work includes the TaxonConcept project[31], focusing on aggregating and linking taxon data from different sources. Numerous scientific name repositories[32] are in use in biology and can be used as a basis for species ontologies—we used the name list of BirdLife and the translations of common names from FMNH since they focus on birds.

The novelty of BirdWatch regarding these systems is based on the following ideas: The visualizations are provided in the *spatio-temporal observation context*, based on an proposed observation. Our goal is to help the observer to improve data quality rather than just provide visualization or data mining tools for inspecting the data for, e.g., research purposes. Furthermore, BirdWatch is arguably the first birding support system to use ontologies and the Linked Data approach: our approach therefore has the potential of not only use statistics but also structured knowledge to explain characteristics of birds, identify common misinterpretations between species, and link observation candidates to additional online services, such as identification assistants, Wikipedias, sound registries, and other observation services. The Linked Data approach has been proven useful when aggregating data from distributed, heterogeneous observation repositories in an interoperable way in many fields of application.

A system such as BirdWatch needs to be evaluated at least along the following dimensions: 1) computational efficiency, 2) ease of use, and 3) capability of raising data quality. As for computational efficiency (1), our experiment suggests that using a SPARQL endpoint as a basis scales well up to at least millions of

[23] http://ebird.org/
[24] http://bird.thewildlab.org/
[25] http://www.inaturalist.org/
[26] http://www.projectnoah.org/
[27] http://www.naturegate.fi/
[28] http://www.gbif.org/informatics/discoverymetadata/ipt-and-metadata/
[29] http://rs.tdwg.org/dwc/
[30] https://semtools.ecoinformatics.org/oboe
[31] http://www.taxonconcept.org/
[32] http://gni.globalnames.org/data_sources

observations using ordinary triplestore tools and hardware. The system could also be implemented using, e.g., a REST API (JSON) on a standard database system that scales up even better. However, relational databases are not as flexible as SPARQL triplestores for data aggregation, linking, and querying. Ease of using the interface (2) of the prototype has not been tested systematically, but a few test ornithologists have tried the system out without major difficulties. The interface is in any case quite simple, and pre-filling the Tiira observation form of course helps in reporting without an additional burden. However, we envision that understanding and interpreting the statistical data may be an issue when using the system. One test user, for example, asked why she did not find an observation that she had made earlier in Tiira. The problem was that the data in the system is not updated in real time, but harvested with latency from GBIF. The system should of course be integrated with the actual Tiira system in real time, but this has not been done yet in the demonstration system.

Another issue is that the underlying observational data is by no means complete and it is biased in many ways, because it is based on the observations of the public. For example, consider the monthly statistics of swallows. In springtime there are lots of early reports of the first swallows seen in Finland, but in summertime people lose interest in them because they are quite common and are seen virtually everywhere in southern Finland. The statistical monthly curve therefore goes down but this does not really tell us how common swallows are in summer but only about the number of reported observations. The user must understand this and interpret the data correctly, otherwise the data may guide her to false or too conservative interpretations. The situation is different when using professional surveying datasets where all birds seen are systematically and reliably reported during a time period and within an area. Our approach and system could of course be applied to such datasets, too, by adjusting the interpretation of statistics.

The most difficult evaluation task is to measure whether using a system like BirdWatch actually improves data quality (3) in the long run and how. One possibility to measure this would be to select a set of test users, and record and evaluate their experiences in using the system. For example, the test users could mark up situations where they think the additional information was helpful in some way, e.g., in preventing making an interpretation that after a second thought was wrong. Even if the final objective truth of the observation could not be verified for sure, subjective measurements of this kind would be helpful in determining the usefulness of the system in raising the quality of observations. Evaluating the system in such a setting remains a topic for further research.

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[33] http://www.seco.tkk.fi/projects/finnonto/
[34] http://www.seco.tkk.fi/projects/ldf/

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[35] http://www.envirofi.eu/