Masters Program in **Geospatial Technologies**

CONSERVATION GIS: ONTOLOGY AND SPATIAL REASONING FOR COMMONSENSE KNOWLEDGE

Mahesh Pathak

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Universidade NOVA · Universitat Jaume I · Westfälische Wilhelms-Universität Münster

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Dissertation supervised by:

Professor Marco Painho, PhD

Instituto Superior de Estatística e Gestão de Informação
Universidade NOVA de Lisboa,
Lisbon,Portugal

Dissertation co-supervised by:

Professor Werner Kuhn, PhD

Institute for Geoinformatics,
University of Muenster,
Muenster, Germany

Professor Carlos Granell Canut, PhD

Institute of New Imaging Technologies
Universitat Jaume I,
Castellón, Spain

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To my

Late Father

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ABSTRACT

Geographic information available from multiple sources are moving beyond their local context and widening the semantic difference. The major challenge emerged with ubiquity of geographic information, evolving geospatial technology and location-aware service is to deal with the semantic interoperability. Although the use of ontology aims at capturing shared conceptualization of geospatial information, human perception of world view is not adequately addressed in geospatial ontology. This study proposes 'Conservation GIS Ontology' that comprises spatial knowledge of non-expert conservationists in the context of Chitwan National Park, Nepal.

The discussion is presented in four parts: exploration of commonsense spatial knowledge about conservation; development of conceptual ontology to conceptualize domain knowledge; formal representation of conceptualization in Web Ontology Language (OWL); and quality assessment of the ontology development tasks. Elicitation of commonsense spatial knowledge is performed with the notion of cognitive view of semantic. Emphasis is given to investigate the observation of wildlife movement and habitat change scenarios. Conceptualization is carried out by providing the foundation of the top-level ontology- 'DOLCE' and geospatial ontologies. Protégé 4.1 ontology editor is employed for ontology engineering tasks. Quality assessment is accomplished based on the intrinsic approach of ontology evaluation.

Results show that human perception and community narratives about conservation comprise accumulated knowledge from everyday experiences but remain abstract with respect to spatial and temporal representation. Foundations of domain ontology on top-level ontology permit the establishment of the semantic connection between human perception of conservation and existing models of geographic and temporal representation in the geospatial domain. With the formal structuring of commonsense knowledge about conservation using description logic, proposed ontology is capable to infer new knowledge based on the conceptualized domain knowledge.

KEYWORDS

Commonsense spatial knowledge

Conservation GIS

Geospatial ontology

Ontology engineering

Spatial cognition

ACRONYMS

BWC- Beeshazar Wetland Complex

CNP- Chitwan National Park

CWA- Close World Assumption

DNPWC- Department of National Parks and Wildlife Conservation

DOLCE- Descriptive Ontology for Linguistic and Cognitive Engineering
e.g.- *exempli gratia* (for example)

GIS- Geographic Information System (s)

i.e. - '*id est* (that is)

NTB- Nepal Tourism Board

OWA- Open World Assumption

OWL- Web Ontology Language

RCNP- Royal Chitwan National Park (former name of CNP)

Sq.Km.- Square Kilometre

UNESCO- United Nations Educational, Scientific and Cultural Organization
VGI- Volunteered Geographic Information

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1. INTRODUCTION

1.1 Study background

The development of spatial meaning in an environmental context requires an interpretation of both physical and social components of the world as it is observed or perceived (Beck, 1967; Golledge, 2002). Knowledge about the physical environment acquired and used without rigorous efforts are considered as the commonsense knowledge of space (Kuipers, 1978).Thinking about space and reasoning provides the basis for understanding spatial pattern and behavior of the real world phenomena (Syfert, 2009). Geographic information is meant to help people to understand the spatial, temporal and thematic attributes of the event and process of the earth surface (Montello, 2009). However, the way real world phenomena have been modeled and manipulated in GIS is contrary to peoples' experience and conceptualization of space (Freundschuh and Egenhofer, 1997).

Evolving technologies and online services are dramatically changing the ways of producing, using, obtaining and sharing geographic information (Elwood, 2008). Ubiquity of geospatial information can be seen in a variety of circumstances and essential in all aspect of the human activities (Painho, 2007 a). Advances in location-aware technologies, web mapping, and wiki-based collaboration have now outpaced the classical spatial data infrastructures as well as widened the usage scenario around the world (Goodchild, 2007; Craglia et al. 2008; Coleman, Georgiadou, and Labonte, 2009). Volunteer Geographic Information (VGI) and 'crowdsourcing' evolved around the world are some examples and collectively termed as 'neo-geography' (Goodchild, 2009). One of the major challenges posed by new possibilities arising from the interconnected world and increasing availability of geographic information is to deal with interoperability of geospatial information (Fonseca, Câmara and Monterio, 2006).

The discourse of ontology in the geospatial domain has begun to deal with the interoperability of geographic information. The use of ontologies for modeling geographic information aims at capturing shared conceptualizations of specific user communities and thus improves interoperability among different geographic databases (Smith and Mark, 1998). However, most of the conceptualization is concerned with the world view that is modeled in existent data and the human perception of the world view is still missing. To make the geographic information more useful and usable, ontology needs to address the human activities and their conceptualization of geographic space (Kuhn, 2001).

1.2 Motivation

Conservation planning is inherently spatial (Pressey et al., 2007) and biodiversity occurs at a variety of geographic scales (Poiani et al., 2000). Knowledge required for biodiversity conservation and conservation planning are fragmented (Hammond, Moritz and Agosti, 2008). Technical knowledge derived from systematic observations and experiments consists of limited environmental facts. Integration of local knowledge using spatial framework can complement the technical knowledge (Petch, Pauknerova and Heywood, 1995). However, GIS applications still lack the mechanisms for the integration of spatial knowledge about biodiversity resource obtained from multiple sources (Balram, Dragićević and Meredith, 2004).

The conservation field is not an exception from the growing availability of geographic information. Furthermore, there exist inherent complexities such as vagueness, spatiotemporal changes and processes of environmental phenomena. Paradigm shift of conservation approaches from ‘classical’ to ‘neo-populist’ has emphasized the community-based conservation practice. Peoples’ perception and commutative narratives have become central towards the integrated conservation and development projects (Blaikie and Jeanrenaud, 1997; Brown, 2002). In this regard, exploring the contextual meaning of the geospatial information about conservation contributed by non-expert users such as VGI and crowedsourceing is an emerging challenge.

This research proposes a term ‘Conservation GIS Ontology’ that comprises the conceptualization of spatial knowledge of non-expert conservationists and conservation narratives from Chitwan National Park, Nepal. The main motivation of this study is to enrich the use of geographic information about conservation scenario contributed by non-expert conservationists. Consequently, growing availability of geographic can support for better understanding of the environmental phenomena and their consequences on biodiversity conservation.

1.3 Research questions

In consideration of the study background and motivation, this study will attempt to answer the following research questions.

- How can the use of ontology support the collection and conceptualization of conservation narratives and community knowledge?

- Are the considerations of spatiotemporal representation in the geospatial domain enough to ground the dynamic conservation phenomena perceived by non-expert conservationists?
- Is the formal knowledge representation language is adequate to support semantic reasoning on human perception about conservation phenomena?

1.4 Objectives

The main objective of this study is to conceptualize the commonsense spatial knowledge about conservation. The specific objectives are:

- Explore the spatial knowledge of non-expert conservationists.
- Design a conceptual ontology to conceptualize the commonsense knowledge about conservation.
- Build a logical ontology for the formal representation of commonsense knowledge to describe conservation scenarios.

1.5 Research approach

The main foundation of this research is based on the argument that -'model-theoretic view of semantics underlying in current ontology cannot account for the human conceptualization, cognitive view of semantic is essential' (Kuhn, 2004; Kuhn, 2005). With the consideration of call for ontology grounding by (Kuhn, 2003), this study proposes for the anchoring of geospatial ontology in commonsense knowledge and everyday experience. Explorations of commonsense knowledge assimilate the notion of cognitive map (Tolman, 1948; Kuipers, 1978), image-schemata (Jhonson, 1987; Kuhn, 2007), human spatial cognition (Mark, 1993), perceptual space and cognitive space (Tversky, 1993; Montello, 1993).

The task of ontology development employed in this study combines the approaches of designing conceptual ontology and constructing logical ontology (Kovacs et al., 2006; Goodwin, 2007). Ontology engineering tasks is accomplished using Protégé 4.1 ontology editor. Ontology evaluation is made based on the intrinsic evaluation approaches (Gómez-Pérez, 2004). Validation of the ontology with extrinsic approaches and inclusion of the expert knowledge about conservation scenario are beyond the scope of this study.

1.6 Contribution

In contrast with the model-theoretic semantic view underline in ontology, novelty of this study is the elicitation of commonsense spatial knowledge about conservation scenario to build geospatial ontology. Based on the outlined objectives and research approach, the major contributions of this study are:

(i) The study provides a framework for exploring community narratives and commonsense spatial knowledge to enrich the understanding about events and processes of conservation (section 4);

(ii) An integrated approach to combine the human conceptualization of conservation with geospatial ontology (section 5);

(iii) A domain ontology-'Conservation GIS Ontology' that comprises spatial knowledge about conservation perceived by non-expert conservationists (section 6, 7)

1.7 Thesis structure

This study comprises eight chapters. The first chapter provides the research background, motivation, objectives, research approach and major contribution areas of this study. The second chapter presents the basic theoretical backgrounds that underlie this study. Relevant studies and their theoretical and methodological discussions are summarized in terms of commonsense spatial knowledge, geographic representation and ontology. The third chapter describes research methods which are essential to fulfill the objectives of the study. The fourth chapter highlights the context of the study through an overview of biophysical environment, conservation narratives and the commonsense spatial knowledge about conservation. Chapter five is about the development of the conceptual ontology and comprises the conceptualization of conservation scenarios perceived by non-expert conservationists. Chapter six describes the methods for converting conceptual ontology into logical ontology. A step-by-step process for authoring logical ontology in OWL using Protégé 4.1 ontology editor is presented. Chapter seven comprises the evaluation of the ontology and some limitations with respect to ontology engineering tasks. The last chapter of this study provides an overall summary, conclusion and the future research work in this direction.

2. LITERATURE REVIEW

The literature review summarized in this section is primarily based on the theoretical and methodological guidelines that are relevant for combining the multidisciplinary concepts underlying in this study. This discussion is presented in three parts: commonsense knowledge about space; representation of geographic information; and ontology.

2.1 Commonsense spatial knowledge

In simplest terms, commonsense knowledge indicates the collection of information or facts that an ordinary person is expected to know. Encyclopedia[1] defines commonsense knowledge as - 'routine knowledge we have of our everyday attitudes'. Knowledge of space represents the accumulation of facts about the spatial arrangement and interactions comprising human-environment relations and recognition of fundamental concepts. Such knowledge is incidental and informally acquired during our everyday experience (Golledge, 2002). People's perception of space, spatial cognition and spatial behavior are experience-based (Freundschuh and Egenhofer, 1997). Development of spatial knowledge is an interpretation of the physical and social component of the world as they are observed or perceived (Beck, 1967). The brain captures such state of experience and integrates them with a multimodal representation stored in memory. When the knowledge is needed, instances of multimodal representation are reactivated (Barsalou, 2008).

Study about commonsense knowledge extends over various disciplinary fields. The main concern in this study is towards the human conceptualization of space and their representation in the geospatial domain. Studies concerning commonsense spatial knowledge are presented in two categories: 'cognitive perspective' and 'computational perspective'. The first category is related with the philosophical point of view to characterize the commonsense knowledge. The second category is about their representation in computer environment.

2.1.1 Cognitive perspective

The basic concept underlying the process of spatial cognition was presented by Tolman (1948) as cognitive map. Cognitive mapping is a psychological transformation process through which people acquires, stores, recalls and decodes information about the relative location and their attribute in everyday spatial environment (Downs and Seta, 1973).

[1] http://www.encyclopedia.com/doc/1O88-commonsenseknowledge.html

Commonsense knowledge of space is an interesting domain of human knowledge (Kuipers, 1979). Kuipers (1978) characterized the important aspect of cognitive map using three metaphors: 'like a map in head'; 'like a network' and 'like a catalog of routes'.

Mark (1993) discussed spatial knowledge in terms of 'obvious' and 'subtle' ways of human spatial cognition. 'Obvious' way is about our everyday interaction with a wide range of geographic concepts and features in real time. The 'subtle' is less obvious but provides great spatial basic for many metaphors that helps us to understand more abstract and conceptual domain. Furthermore, he grouped the geographic knowledge in three categories: declarative; procedural and configurational. 'Declarative' geographic knowledge describes the facts about the location. 'Procedural' geographic knowledge is about the ability of people to find their ways from place to place and perform tasks. 'Configurational' describes the knowledge of geographic space as 'map-like' and often has or approximates a Euclidean geometry.

Mark and Smith (2001) have discussed the common sense world with the reference of 'primary theory' and 'secondary theory' presented by Horton (1982). Primary theory is that part of common sense which exists in all cultures and in all human beings at all stage of development. Secondary theories are the collection of folk beliefs which are characteristic of different economic and social setting. Primary beliefs are related to the 'mesoscopic phenomena' that are immediately accessible to perception and actions. Secondary beliefs are related to the phenomena which are either too large or too small to be immediately accessible to human beings in their everyday perceptions and actions. Meaningful structures for organizing our experience, and the application of current knowledge of schemas to new situations enables people to make sense, learn, and reason about our environment (Freundschuh and Egenhofer, 1997).

Montello (1993) described that people's perception of space and spatial behavior are scale dependent and experience-based which results in the difference in mental maps with others. Tversky (1993) has made distinction between perceptual space and cognitive space with respect to time and space. Perceptual space refers to what can be seen or observed through the senses at one time where as cognitive spaces include larger-scale spaces, which cannot be captured immediately with our sensors and, therefore, must be subsequently put together in order to be understood.

Cognitive research about space and place has identified several issues. Among them, essential for understanding human spatial cognition are: the responses of sensory systems that pick up spatial information; the development of spatial knowledge from birth to adulthood; a people's first exposure to a new place, the accuracy and precision of knowledge; and cognitive structure and process (Montello and Freundschuh, 2005).

Jhonson (1987) has proposed a term 'Image Schemata' to describe the way people use the recurring and imaginative patterns to understand and structure their experiences while moving through and interacting with their environment. Kuhn (2007) has presented the key characteristic of 'Image schema' (Johnson, 1987) and 'image-schematic categorization' (Lakoff, 1987) as a theoretical foundation of cognitive semantics. Furthermore, he argues that activities and process capture by 'Image Schema' and its support for understanding and reasoning about experiences are potential for building the ontologies of spatio-temporal phenomena.

2.1.2 Computational perspective

Computational aspect of commonsense spatial knowledge has emerged as the cognitive research agenda of GIScience to investigate and address the questions surrounding digital geographic information and GIS (Montello, 2009). Human cognition of space is not only dependent on physical environment and time it is often fluid, flexible, and context-dependent. Therefore knowledge representation for computational environment should reflect the situated nature of human understanding (Pike and Gahegan, 2007). Such contextual and situated commonsense knowledge of real word in computational and artificial intelligence perspectives is called naïve knowledge (Yi et al., 2008)

Egenhofer and Mark (1995) have presented the idea of 'naive geography' as a field of study that is concerned with the formal model of the commonsense geographic world. The main focus of the naïve geography is the area of spatial and temporal reasoning, representation in various application domains and the way people use and interact with them. Formal model of commonsense spatial knowledge also provides the basis to design intelligent GIS that can act and respond the way people perform spatio-temporal reasoning.

Harvey et al. (1999) raised the issue of semantic interoperability to navigate the meaning of the different conceptualization and understanding of people and social groups exist in geographic information technology. The transformation of commonsense spatial knowledge from cognitive perspective to computational environment is one of the major challenges in the contemporary GIS. The next section provides an overview of the existing efforts for providing the representation model of the spatial knowledge in terms of geographic information.

2.2 Representation of geographic knowledge

Studies have provided several form of the conceptualization of geographic knowledge and their representation model in GIS. However, there is lack of a comprehensive and widely accepted conceptual model of the geographic space (Nunes, 1991). This section presents the discussion about the representation of geographic knowledge in two parts: mathematical and conceptual. Mathematical notion is related with the argument about the representation of geographic information as vector and raster data model. The discussion towards the perspective of 'object vs. continuous field' and 'fiat and bona fide boundaries' are considered as conceptual representation.

2.2.1 Mathematical notion of geographic representation

Although numerous definitions of geographic information and GIS can be found in the literature, all focus on the concept of geo-referencing (Goodchild, Yuan and Cova, 2007). The traditional approach used in the design of geometric data models are based on the Cartesian coordinate space. These models start from the mathematical basis of points in an infinitely precise space and construct more meaningful concepts as sequences and enclosures of connections of points (Freundschuh and Egenhofer, 1997). Vector and raster has provided the representation model of geographic world during the past four decades (Goodchild, Yuan and Cova, 2007).

Vector GIS is firmly rooted in the view of geography as spatial science, formulated in the 1950's and 60's, which resulted in the geometrization of the geographic world and its reduction to a body of theories about relations between points, lines, polygons, and areas (Couclelis, 1992). One of the problems with this view point is that euclidean points, lines, and polygons do not exist in the natural, full-scale geographic world. They are reasonable approximations of geographic phenomena when modeled at specific scales (Freundschuh and Egenhofer, 1997).

Another form of geographic representation in GIS is raster representation. In this representation geographic world as a vector field of measurable values, discretized into pixel array (Couclelis, 1992). This representation model has became popular among the uses looked for by powerful analytical tools where generation of data was simple easy and cheap (Nunes, 1991). Raster-based GIS is strongly supported by the increasing importance of satellite imagery not only in geography, but in wide areas of applied natural science (Couclelis, 1992).

2.2.2 Conceptual notion of geographic representation

In terms of the conceptual notion of geographic representation, literatures are basically found in two perspectives: 'discrete object vs. continuous field' and 'fiat and bona fide boundaries' Peuquet (1988) has pointed out the duality of discrete objects and continuous field as distinction between location-based and object-based representation. Couclelis (1992) argued that the field/object distinction is fundamental to our understanding of the world around us and strongly related to human perception. Humans clearly perceive the world around them as populated by discrete objects, to which they give names and ascribe behaviors (Goodchild, Yuan and Cova, 2007). Egenhofer et al. (1999) brought this varied argument on object vs. field representation as an issue of interoperability in GIS. As a solution, (Cova and Goodchild, 2002) have proposed a hybrid concept in which every point in geographic space mapped not to a value but to an entire discrete object.

Discourse on the geographic representation as 'fiat' and 'bona fide' boundary primarily emerged with the realization to distinguish the geographic information represented in GIS in terms of physical environment and social environment. In simple terms, 'fiat' boundaries are defined by human beings and 'bona fide' boundaries are physical objects that exist in real the world (Smith and Varzi, 2000). Smith (1995) argues that 'bona fide' and 'fiat' objects represent the geographic world in two types of completely bounded objects. 'Bona fide' boundaries include physical realities such as riverbanks and coastlines; these would exist even in the absence of all human efforts of delineation or conceptualization. On the other hand, 'fiat boundaries', owe their existence to acts of human decision, administration, or fiat, to laws or to political decrees. Political and administrative units, national and state borders, and property boundaries are all examples of human-created objects.

2.3 Ontology

The word "ontology" has gained popularity within the knowledge engineering community. However, its meaning tends to remain a bit vague, as the term is used very differently among various disciplines (Guarino and Giaretta, 1995). This section presents some definition of ontology in general and particular emphasis is given to the context of geospatial domain.

2.3.1 Origin and definition

Gruber (1993) has defined the ontology as:

> "Ontology is an explicit specification of a conceptualization."

The definition was made from the philosophical perspective where ontology is the systematic account of existence. Guarino (1998) distinguished ontology in the philosophical sense and in the context of Artificial Intelligence (AI). In the philosophical arena, ontology is characterized as a particular system of categories for specific view of world. In AI, ontology is an engineering artifact that describes a certain reality with a specific vocabulary using a set of assumptions (Fonseca, Martin and Rodriguez, 2002). Smith (1998) describes ontology in terms of reality base ontology(R-Ontology) and epistemological ontology (E-ontology). R-ontology is a theory about how the whole universe is organized, and corresponds to the philosopher's point of view. E-ontology, on the other hand, fits the purposes of software engineers and information scientists, and is defined as a theory about how a given individual, group, language, or science conceptualizes a given domain. ontology is the study of the categories of things that exists or may exist in some domain. Guarino (1998) describes ontology as a logical theory accounting for the intended meaning of a formal vocabulary. Furthermore, based on generality, he has proposed three levels of ontology: top-level, domain and task, and application. Top-level ontology describes very general concepts such as space, time, matter, object event, and action which are independent of a particular problem. Domain ontology and task ontology describes the vocabulary related to a generic domain or generic activity with its foundation on top-level ontology. Application ontology describes the concepts depending on particular domain task to perform certain activities. Figure 1depicts the level of ontology and dependencies.

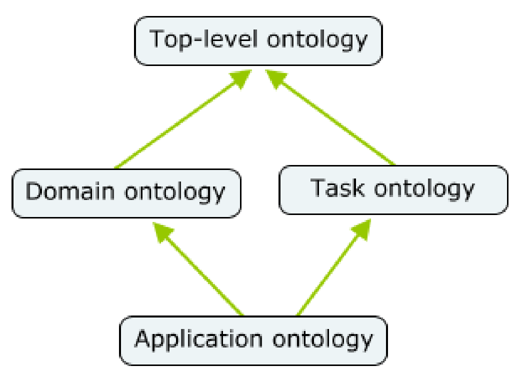

Figure 1: Level of ontologies and their dependence (Guarino, 1998)

Based on the review of selected literature, Agarwal (2005) has pointed out the three primary component of ontology: axioms, class or category, and relations. Axioms are used to model conditions that are always true for domain. Category or class is a set of object and basis of knowledge representation in ontology. Relations represent types of interactions between the classes. Ontology aims at providing a consistent formal theory of tokens (instances) and types (kind) of the real world and the relation and process that change them (Painho, 2007 b)

2.3.2 Ontology of geospatial domain

With the advancement of GIS and GIS-related applications on the World Wide Web and as well as everyday activities, there is an ever-increasing need to know how non-experts conceptualize the geographic domain (Mark and Smith, 2001). In such emerging scenario, there are now many proposals for describing space, spatial relationships, and relations between entities and their locations that have been developed within broadly 'ontological' frameworks (Bateman and Farrar, 2004). The purpose of using ontology in GIScience is to define a common vocabulary that will allow interoperability and minimize any problems with data integration, both from different systems and between user and system (Agarwal, 2005). The diversity of field covered in a geo-ontology make GIS ontologically more demanding than traditional systems (Frank, 2001). One of the main concerns of ontology in the geospatial domain is to contribute for building better information systems (Kuhn, 2001).

Frank and Raubal (1999) have given emphasis on the formalization of spatial relation in geographic space which is crucial for further advancement, standardization and interoperability of GIS. Wang et al. (2007) argues that the consideration of theoretical basis of geographic space can only make the spatial information model more semantic and consistent. (Henriksson, Kauppinen, and Hyvönen, 2008) describes the geospatial ontology correspond to the physical and social world having location on the surface on earthen and their semantic and spatial relationship.

Arpinar et al. (2006) pointed out the importance of geospatial semantic for performing spatial queries using imprecise spatial and temporal references (e.g. near , far , around noon) for analyzing geospatial-semantic associations using textual and other non-metric information. This can also help with effective geographical knowledge discovery. Several elements are required when developing geospatial semantic that support effective spatial reasoning. These include the use of qualitative modifiers, proxy place names, spatial references and spatial relation describers.

Geospatial information has radically changed in the past decades. Previously, geographic information was collected, processed and analyzed in the context of the respective community of a disciplinary field. Now information about geographic phenomena are retrieved and combined in an ad hoc way from anywhere in the world and escaping their local context (Kuhn, 2005). Such changes have lead to a number of challenges for dealing with spatial information in the geospatial domain (Fonseca, Egenhofer and Davis, 2000)

2.3.3 Ontology grounding

Consideration of ontology grounding in geospatial domain has emerged in the context that the existent model-theoretic view of semantic cannot account for human conceptualization and hence cognitive semantic view of the real world is required (Kuhn, 2003). The main argument of cognitive semantic is that language needs to be studied in the context of human cognitive, ability and social setting which functions as means of communicating ideas such as gestures, diagrams, procures, maps, mathematical symbols, computer program and so on (Kuhn, 2004). Grounding gives meaning to ontological primitives by relating them to qualities outside the symbol (Kuhn and Raubal, 2003). Cognitive semantic is more interested in process (actions, events or other dynamic phenomena) and their role in producing meaning than traditional linguistic and formal semantic (Kuhn, 2004).

2.3.4 Basic primitives of geospatial ontology

The main essence of this discussion is to provide an overview of the essential components of geospatial ontology that makes the geographic information more meaningful among various application domains. Several arguments have been made for describing geospatial ontology, this section presents an overview in terms of geographic space and spatio-temporal change.

2.3.4.1 Geographic space

According to Spaccapietra, Cullot and Parent (2004), ontologies of space defines the concepts that are used in specifying space, spatial elements (eg., point, line polygon), spatial relationship. Fonseca, Câmara and Monterio (2006) proposed two basic concepts of geo-ontology: (a) concepts that correspond to physical phenomena in the real world; (b) concepts that correspond to features of the world that we create to represent social and institutional constructs. The first one is termed as 'physical concepts' and second one is 'social concepts'. Hierarchies of geo ontology comprise perspectives of conceptual representation of geographic information, i.e. 'discrete object' and 'continues field'; 'bona fide objects' and ‘fiat objects’. Frank (2001) has proposed that the components of geo-ontology may be categorized into five tiers. Tier 0, assumes an external reality consisting of a space-time set of continuous fields. Tier 1, is composed of the measurements of this reality by humans and their instruments. Tier 2 consists of objects which are formed by humans based on measurements. Tier 3 is the set of objects of social reality constructed by agreements and contracts. The last one, Tier 4, is composed on subjective concepts about space.

2.3.4.2 Spatio-temporal particular

With the growing concern for addressing the event and process of real world phenomena, emphasis of geospatial ontology is moving towards addressing spatiotemporal change. Galton (2003) argues that ontologies in GIS must embrace a fully spatio-temporal view of the world which should include: spatial object and field; temporal object and field; and location. The temporal analogies of objects are: events and process of various kinds. Location may be both purely spatial location (regions, lines and points) and purely temporal location (interval and instants). For full consideration of spatio-temporal view, it is essential to consider spatio-temporal location.

A Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) is a top-level ontology dealing with spatiotemporal particulars. The assumption made for DOLCE is that different entities can be co-located in the space-time. Physical and non-physical entities are discussed as enduring and perduring entities (endurants and perdurants). The main difference is associated with their behavior in time. Endurant are wholly present at any time they are present. Perdurants are just extended in time by accumulating different temporal parts (Masolo et al., 2002).

According to Grenon and Smith (2004) endurants are analogous to snapshots of reality and perdurants are analogous to videos spanning time. Bittner and Smith (2002) has presented the four-dimensionalist ontology to describe the perspective of observation spanning the whole reality from beginning to end and from one spatial extremity to the other. This theory is divided into two major categories: ‘SNAP’ and ‘SPAN’. ‘SNAP’ ontology comprises enduring entities such as substances, qualities, roles and functions. ‘SNAP’ entities are related to space by locational relation and to time by a relation of existence at a time. ‘SPAN’ ontology comprises entities such as process and their parts. ‘SPAN’ entities are subjected to spatio-temporal and temporal locational relations (Bittner and Smith, 2002; Grenon and Smith, 2004).

However, the ontology of geography domain is being elaborated by the corresponding communities, spatio-temporal ontologies are in their infancy. There is still a lack of appropriate definition capable of dealing with space, time and suitable reasoning (Spaccapietra, Cullot and Parent, 2004).

2.3.4.3 Basic theories of geospatial ontology

Casati, Smith and Varzi (1998) have classified the theory of spatial representation for describing the geospatial ontology into four main categories: regions of space; absolute vs. relational theories of space; types of spatial entities; and boundaries and vagueness. Furthermore, theoretical tools essential for developing theory of spatial representation are described in terms of mereology, location and topology. Mereology is a first-order theory constructed around the primitive *'is a part of'* which involves a major part of our reasoning about space. Location describes the general theory of spatial location needed over and above mereology in order to permit the investigation of the relation between a geographic entity and the reason of space. Topology provides the semantic account of relation which goes beyond the plain 'part-whole relation'. Bishr and Kuhn (2000) also pointed out the theories essential for geospatial ontology as: theory of topology; theory of mereology; theory of identity; theory of categories; and theories of dependence.

2.3.5 Ontology engineering

Ontological engineering encompasses a set of activities conducted during conceptualization, design, implementation and deployment of ontologies (Mizoguchi, 1998; Devedzić, 2002). The creation of ontology is s a knowledge acquisition task which involves eliciting, analyzing and interpreting human expert knowledge, and transferring this knowledge into a suitable representation (Mizen, Dolbear and Hart, 2005).

Ontologies are becoming increasingly popular in practice (Guarino and Welty, 2000). Until now, several of ontologies have been developed by different groups, under different approaches, and using different methods and techniques. However, a few works have been published about how to proceed, showing the practices, design criteria, activities, methodologies, and tools used to build them (Fernandez,Gomez-Perez and Juristo, 1997).

One of the most important and critical questions when starting a new ontology is determining what things there are in the domain to be modeled (Masolo et al., 2002). Some basic essential elements that requires thorough understanding during ontology engineering are: ontology language standards, ontology logics and ontology editors

2.3.5.1 Ontology language and standards

Ontology languages allow users to write explicit formal conceptualizations

of domains models (Antoniou and Harmelen, 2009). Several ontology languages have been developed during the last few years and their foundation are basically on: Extensible Markup Language (XML) syntax; Resource Description Framework (RDF) and RDF Schemas. XML was designed to be a simple way to send documents across the 'World Wide Web'. It allows anyone to design their own document format and then write a document in it (Geroimenko, 2006). RDF defines a general common data model that adheres to web principles (W3C 2001). RDF schema allows a designer to define and publish the vocabulary used by an RDF data model, i.e. define the data objects and their attributes (Gomez-Perez and Corcho, 2002)

Web Ontology Language (OWL)[2] is built on RDF and RDF Schema and aim to be the standardized and broadly accepted ontology languages of the semantic web (Antoniou and Harmelen, 2009). OWL consists of three languages: OWL Lite, OWL DL and OWL Full. OWL DL was designed to support the existing Description Logic which has desirable computational properties for reasoning systems[3]. OWL Lite is the simplest language and OWL-DL is a DL language with markup syntax. OWL Full has been developed to totally include the semantic of the previous RDFS (RDF Schema) standard (Horrocks, 2005).

2.3.5.2 Logics and axiom

Although several logics have been used in ontology language, description logics (DL) are appearing as the leading formalism for the development of ontology (Spaccapietra, Cullot and Parent, 2004). Description logics are a family of knowledge representation languages that focus on describing the semantics of concepts, and using inference to automatically classify new concepts in the concept hierarchy and to check non-contradiction among specifications (Horrocks, 2005). The basic inference on concept expressions in Description Logics is subsumption (Nardi and Brachman, 2003).

DL languages vary in expressive power, depending on the building operators that are retained for the language. In DL system, a knowledge base consists of a Terminology Box

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[2] http://www.w3.org/TR/owl-ref/
3 http://www.w3.org/TR/2004/REC-owl-guide-20040210/#OwlVarieties/

(T-Box) and Assertional Box (A-Box).T-Box describes conceptual knowledge terms of concepts, roles and restriction and A-Box holds the knowledge about the instances (Spaccapietra, Cullot and Parent, 2004).

2.3.5.3 Ontology editors

Ontology editors are tools that enable inspecting, browsing, codifying, and modifying ontologies and support the ontology development and maintenance tasks. Existing editors vary in the complexity of the underlying knowledge model, usability, scability, etc. nevertheless, all of them provide enough support for the initial ontology development (Stojanovic and Motik, 2002). Recently there are several ontology editors available for authoring ontology[4], one of them is Protégé Ontology Editor. Protégé is a free, open-source platform that provides a growing user community with a suite of tools to construct domain models and knowledge-based applications with ontology[5].

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[4] http://www.xml.com/2002/11/06/Ontology_Editor_Survey.html

[5] http://protege.stanford.edu/overview/index.html

3. METHODOLOGY

This section comprises the conceptual and analytical framework that directs the interpretation, analysis and discussion to respond to the research issue and to meet the objectives of the study.

3.1 Conceptual framework

The following conceptual framework provides an overview about how the theoretical discussions (presented in section 2) are aligned with the tasks essential to fulfill the objectives of the study. The conceptual framework (Figure 2) comprises three components: ontology, cognition and representation.

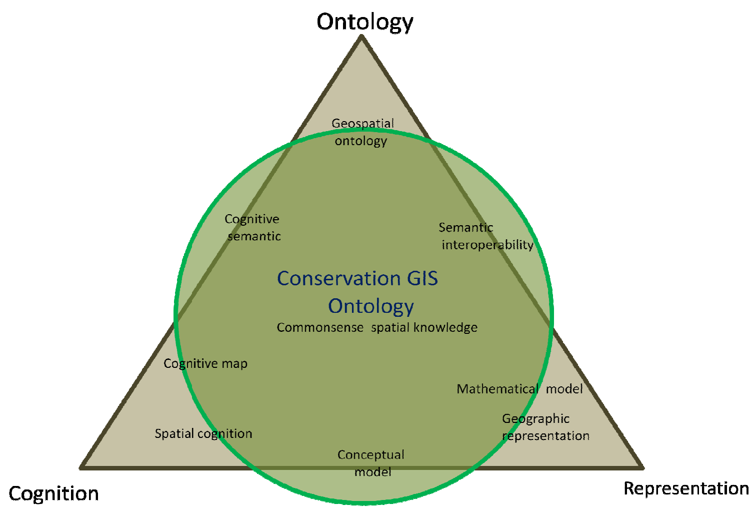

Figure 2: Conceptual framework of the study

Figure 2 depicts that 'Conservation GIS Ontology' is built upon commonsense spatial knowledge and has foundations in the concepts of spatial cognition, geographic representation and geospatial ontology. Commonsense spatial knowledge about conservation phenomena is the core component for describing the domain knowledge represented in this ontology. Discussion about commonsense knowledge is presented with reference to the concepts of spatial cognition (section 2.1). These concepts provide the theoretical guidelines for exploring and managing the commonsense spatial knowledge about conservation phenomena as per the requirement of ontology development tasks. The main focus is on the notion of cognitive semantic in the geospatial domain. Concepts regarding to conservation and their representation as geographic information are fundamentals for the formal representation of human perception about conservation scenarios (section 2.2). Conceptual and methodological arguments about ontology (section 2.3) provides a framework for the consideration of commonsense spatial knowledge to design 'Conservation GIS Ontology'.

3.2 Analytical Framework

The analytical framework of this study is designed by combining the cognitive and computational aspects of ontology development. The cognitive aspect is concerned with the exploration of community narratives and spatial knowledge of non-expert conservationists. On the other hand, the computational aspect deals with converting the domain knowledge into natural language expression and thereafter into a machine readable language. Analysis of the study is primarily based on two tasks: exploration of commonsense spatial knowledge and ontology development. The main processes and steps employed in this study are summarized in figure 3.

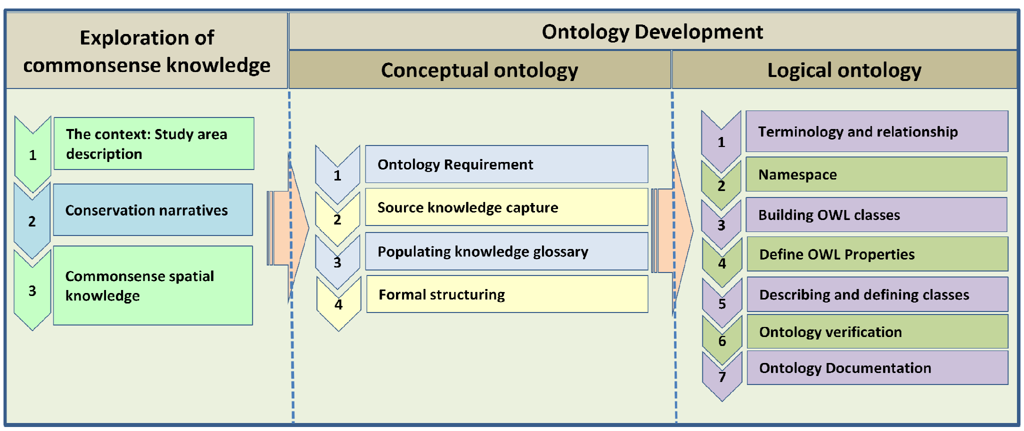

Figure 3: Analytical framework of the study

3.2.1 Exploration of commonsense knowledge

Commonsense spatial knowledge about conservation scenario presented in this study are based on the field work carried out as a part of the community-based biodiversity resource inventory initiatives in Beeshazar Wetland Complex, Chitwan National Park, Nepal (study area map in Figure 5). Although the field work was not intended for this study purpose, interview and communication with the local people and key-informants is conducted to enrich the information required to conceptualize the domain knowledge and ontology development tasks. The context and source of the commonsense knowledge are as follows.

3.2.1.1 The context of the knowledge

Commonsense knowledge discussed in this study represents the conservation scenario of the Chitwan National Park (now onwards referred as CNP) from the community knowledge perspective. Such knowledge concerns only with the spatial information that makes sense to be represented as geographic object or geographic information. For example, knowledge about wildlife movement comprises of information about wildlife name, observed location and observation time. Such commonsense spatial knowledge regarding to the conservation scenario are broadly categorized as: wildlife, habitat, human activities, institution policy, disaster, and natural environment. Descriptions of each category are provided with reference to the knowledge of non-expert conservationists and do not bear the complete list in the context of scientific vocabulary or taxonomy.

3.2.1.2 Source of information

Non-expert conservationists are the key informants of this study. Tourist guides, park guards, community forest guards, members of local youth clubs and informal intuitions and local people are considered as non-expert conservationists. Human perception and spatial knowledge about conservation scenario were explored during the 'map reading' training and 'Community GIS' training (some photographs of field work are provided in Appendix- 1) conducted to enhance the spatial thinking of local community to support the biodiversity resource inventory. Some sketch maps displayed as tourist guide information were also collected (Figure 4). Information depicted on such maps and community narratives to describe wildlife movement, habitat change, human disturbance and environmental phenomena was verified with reference to relevant literature, annual reports, Google Earth images, aerial photographs and topographic map of the study area. Furthermore, historical scenarios were collected through in-depth interviews with the key informants such as experienced tourist guides. Information related to biodiversity resources and some facts and figures about the wildlife population were collect from the existing literature as well as annual reports of the CNP.

Figure 4: Sketch map showing the community forest area in the buffer zone of CNP

3.2.2 Ontology development

This section describes the step-by-step process for the formal representation of commonsense knowledge about conservation. Ontology development task is primarily based on the ontology development guidelines prepared by Ordinance Survey (Hemsley, 2003; Kovacs et al., 2006; Hart and Goodwin, 2007; Goodwin, 2007), the ontology development guidelines described in METHONTOLOGY (Fernandez, Gomez-Perez and Juristo, 1997) and tutorial for authoring OWL Ontology using Protégé4.1 (Horridge et al., 2009).

METHONTOLOGY presents the set of activities that confirm the ontology development process. This method discuss about life cycle of ontology development process to build ontologies from scratch. Ontology development method comprises: specification; knowledge acquisition; conceptualization; integration; implementation; and evaluation.

The methodology provided by Ordnance Survey comprises two phases for constructing domain ontology: conceptual and logical ontology. Conceptual ontology is an organized way of representing domain knowledge and it is written in natural language. On the other hand, logical ontology contains the machine understandable descriptions about a specific domain and provides the potential for data service interoperability (Kovacs et al., 2006). Major steps and tasks required for developing conceptual ontology are summarized in table 1.

Step	Process	Major tasks
1	Ontology requirement specification	• Formulated the completeness and consistency questions • Define the scope and purpose of ontology • Ask for the completeness and consistency of key objects
2	Source knowledge capture	• Note down the concept terms and relationship terms of the domain knowledge • Collect the supplementary documentation that satisfies the purpose and scope of the ontology
3	Populating knowledge glossary	• Provide the descriptive information of the concept terms • Provide the meaning of concept and relationship terms in natural language and
4	Formal structuring	• Open World vs. Closed World Reasoning • Relationship rules, relationship characteristics and modifiers • Capturing loss of information
5	Evaluation and Documentation	• Conceptual ontology evaluation criteria • Documentation

Table 1: Steps for developing domain ontology (summarized from Kovacs et al., 2006)

4. COMMONSENSE SPATIAL KNOWLEDGE ABOUT CONSERVATION

This section describes the commonsense spatial knowledge of conservation in the context of Chitwan National Park (CNP), Nepal and discussion is presented in three parts. The first part highlights the biophysical environment of the study area. The second part narrates conservation practices with respect to historical context and emerging challenges. The third part depicts the spatial knowledge of non-expert conservationists regarding the conservation scenario.

4.1 Study area

4.1.1 General introduction

CNP is situated in the central 'Terai' and 'Siwalik' region of Nepal. The CNP was established in 1973 as the first National Park in Nepal. Currently it comprises 1682 sq km (932 sq km as national park and 750 as buffer zone). In 1984, CNP scribed on the World Heritage list under natural criteria VII, IX and X. In 2003, 'Beeshazar and Associated Lakes' of its buffer zone was designated as a Wetland of International Importance under the Ramsar Convention (Bhuju et al., 2007). CNP is administrated by the park management committee under the Department of National Parks and Wildlife Conservation (DNPWC) of the Ministry of Forest and Soil Conservation[6].

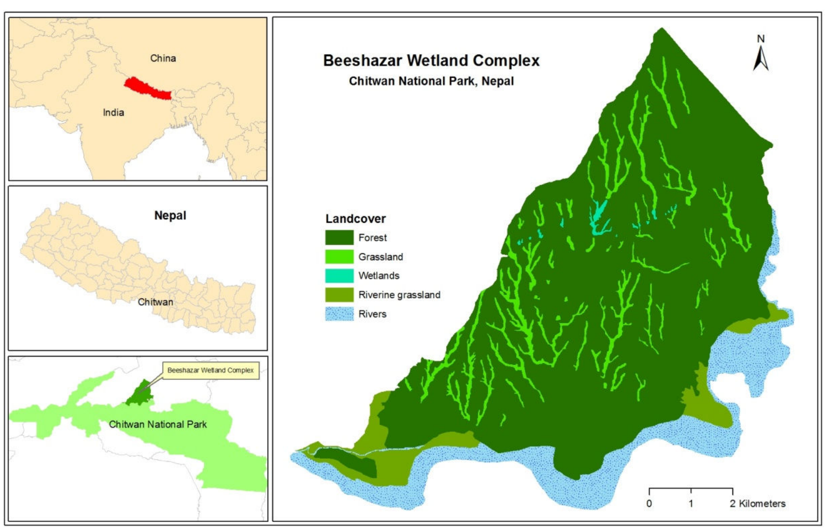

Figure 5: Map of the study area

6 http://www.dnpwc.gov.np/national-parks-chitwan.asp

4.1.2 Physical and climatic environment

Chitwan National Park lies in the flood plains of the central Terai region of Nepal. The flood plains are a series of ascending alluvial river terraces by Naryani River and its tributaries. Climatic conditions are subtropical with a summer monsoon from mid-June to late-September and a relatively dry winter from October to February. The monsoon rains cause dramatic floods and alterations of river courses. Temperatures are highest, with a maximum of 38°C, during summer,- and drops to a minimum of 6°C, after the monsoon (Nakarmi, 2007; UNESCO, 2008).

4.1.3 Biodiversity resources

In the local language 'Chitwan' means 'the forests where leopards dwell' (NTB, 2009). This indicates that CNP is rich in biodiversity resources. This area is one of the largest effective protected areas in the lowlands of the Indian subcontinent; as such it is very important for international conservation (UNESCO, 2008).CNP is home to many endangered and globally threatened species. Nine hundred and nineteen species of flora are estimated in CNP. There are more than 50 different grass species, including elephant grass. The park is home to 58 species of mammals, 539 species of birds, 56 species of reptiles and amphibians, and 124 species of fish. Some of the important mammals species are rhino (rhinoceros), tiger, elephant, antelope and leopard. Major reptiles are crocodile, golden monitor lizard and python. Bird species found in CNP include the Black necked stork, the Lesser adjutant stork, Grey headed fishing eagle, Brahmini ducks, the Bengal florican and the Giant hornbill (Bhuju et al., 2007).

UNESCO[7] describes the importance of the biodiversity of CNP as:

> *Chitwan is one of the few remaining undisturbed vestiges of the Tarai region, which formerly extended over the foothills of India and Nepal. It has a particularly rich flora and fauna. One of the last populations of One-horned Asiatic rhinoceros lives in the park, which is also one of the last refuges of the Bengal tiger."*

4.2 Conservation narratives

The term 'conservation narrative' is used to characterise the conservation practice, its consequence on biodiversity resource and response by local community in the context of CNP. Referring to the explanation of conservation strategy by Brown (2002), the paradigm

[7] http://whc.unesco.org/en/list/284

shift of conservation practice in CNP can be characterised from 'the classic approach' (local people as direct threat to biodiversity) to the 'populist approach' (participation and empowerment of local people as a key to finding solutions to more sustainable use of biodiversity) and recently towards the 'neo-liberal approach' (adding economic value to biodiversity such as ecotourism).

This section aims to depict the interplay between the natural environment and biodiversity resources with the presence of human activities in the CNP. The main purpose for describing the conservation narratives is to capture the knowledge about the spatial thinking and reasoning made by local people and stakeholders in the context of changing socio-economic, environmental and conservation planning scenario over the last six decades. Discussion is presented with reference to historical context and emerging scenario. Historical context presents the response of the local community and stakeholders towards the several conservation practices with reference to the status of the rhino population since l950 (Figure 6). Emerging scenarios is about the requirements of spatial information system to understand the historical and contemporary biophysical environment and their implication for local level conservation planning.

4.2.1 Historical context

CNP has long been one of the country's treasures of natural wonders. Historically, it is one of the dense forest areas in the Nepal and known as *Char Koshe Jhadi* (the forest rich in wildlife).[8] This forest area has been protected since at least 19th century as a hunting reserve for Nepali and foreign aristocrats. During the period of 1846-1951, this area was protected as a royal hunting reserve. It was estimated that the richness of biodiversity resource in this area probably protected more animals than it killed. Because of the warm and temperate climate this area was known as a malaria prone area and unsuitable for human settlement (Gurung, 1983; UNESCO-IUCN, 2003).

After massive malaria eradication programme in 1954 and resettlement provision of government, huge tracts of the forest were cleared to make space for farmland. Because of the excessive loss of habitat, the rhinoceros population declined dramatically during the decade of 1950s (Gurung, 1983). Considering the potential threat to wildlife, the first conservation effort had made through the establishment of Rhino sanctuary in 1957. In 1973, this sanctuary was extended and a total of 932 sq.km. area were declared as Chitwan

[8] http://en.wikipedia.org/w/index.php?title=Chitwan_National_Parkandoldid=209984618

National Park (RCNP, 2000; Paudyal, 2001; Pradhan, 2001). This effort has brought significant improvement on wildlife conservation. One of the major successes after the establishment of CNP was the increase of Rhino population from 165 in 1962 to 376 in 1984 (Adhikari, 2002).

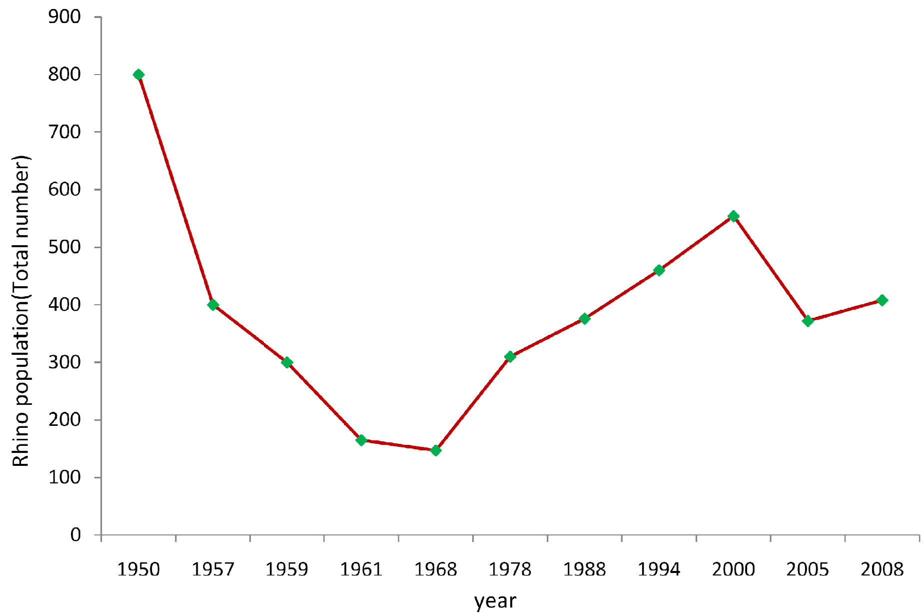

Figure 6: Rhino population in Chitwan National Park since 1950 (Adhikari, 2002; CNP, 2008)

Despite the significant increase in rhino population, the wildlife centred conservation strategy has brought negative attitude of local community towards the conservation initiatives. Local people were restricted to enter the forest. Livelihood activities such as, cattle grazing, fodder collection, firewood collection etc. were adversely influenced. On the other hand, increase in wildlife population (especially rhino population) caused frequent damage on crops and caused death of humans. Communities were neither provided alternate livelihoods options nor did they receive any compensation for the damage caused by wildlife (Heinen and Kattel 1992; Straede and Helles, 2002).

In the mid of 1990s, CNP has been extended to adjoining forest as buffer zone area. This strategy has provided rights for the conservation and sustainable use of buffer zone areas (Budhatokhi, 2001). The local communities started to be involved in the decision making process for conservation planning. Revenue collected from CNP was allocated to the surrounding communities (HMG,1996). Various capacity development programmes and tourism promotion activities were initiated. More emphasis was given to increase community awareness of wildlife conservation and habitat protection (Paudel, 2002). Rhino and Tiger have become symbolic species which local people can be proud of in CNP. Because of the success of community-based conservation strategy, CNP provided home for 554 Rhino in 2000 (Adhikari, 2002).

Since the beginning of the 2000, CNP had experienced new challenges for wildlife conservation. Maoist insurgency in Nepal has begun in the mid of 1990s and reached the extreme after 2000. Most of the army patrolling posts previously scattered in CNP returned back to the headquarters. This situation provided the favorable environment for wildlife poaching activities in CNP and its buffer zone areas (Baral and Heinen, 2005). As a result, during the period of 2000-2005, the rhino population has decreased to 372 population. After the peace process in 2006, the rhino population started to increase again. The National Rhino Census 2008 reported 408 rhino in CNP and its surrounding areas (CNP, 2008).

Although, the conservation narratives highlighted in the above description only depicts the status of the rhino population, this provides an overview to understand the influence of various human activities and institutional policies towards wildlife and habitat conservation. Unfortunately, such historical narratives are sparse and stored in individual mental maps. Most of the conservation narratives from community and non-expert conservationists are the abstraction of their everyday experience and lacks the spatio- temporal reference to integrate with the existent GIS representation.

4.2.2 Emerging scenario

With the adaptation of community-based conservation approach and ecotourism activities in CNP, there is a need for the exploration of conservation narratives and their spatio-temporal references. In the context of GIS, such conservation narratives provide the contextual meaning to enrich the expert knowledge regarding wildlife movement, habitat change and human disturbance and so on. Understanding the complexity of human-environment relationship and their consequences for the wildlife conservation is an emerging issue in the context of climate change scenarios. In this milieu, exploring the community's perception towards the conservation scenario with respect to historical trends and their representation in GIS is essential. Providing the geospatial tools for the non-expert conservationist to manage their spatial information and knowledge about conservation scenarios is an emerging need in the CNP.

4.3 Spatial knowledge of non-expert conservationists

This section aims to explore the conservation narratives with reference to local spatial knowledge. Discussion is presented to depict how knowledge about environmental, human and institutional component is associated with the fluctuation of wildlife population over various spatial-temporal scale. The remaining part of this section provides an overview of the spatial knowledge of non-expert conservationists regarding the wildlife movement, habitat change and spatial reasoning for conservation planning. The description is primarily based on the observation within the Beeshazar Wetland Complex (now onwards referred as BWC).

4.3.1 Wildlife movement

Spatial knowledge about wildlife movement is related with the perception of the rhino movement in different areas of BWC. Example is based on the field work carried out as a part of the map reading skill and Community GIS training provided to the tourist guides, forest guards and members of community forest user groups in CNP and its buffer zone. Participants (non-expert participants) were asked to describe the movement of rhino in BWC. Topographic map of 1:25000 and some printed scene of Google Image was provided as a reference map.

Results are found in two distinct conceptualizations (Figure 7). This study makes use of the results to depict the spatial knowledge of non-expert conservationist towards the wildlife movement. One type of results depicted with the drawing of the lines (movement corridor in Figure 7) shows the perception of rhino movement similar to the concept of wildlife corridor. In this case, the association of rhino movement with respect to the wetland habitat was the main guiding ideas to draw lines by recalling the observation of rhino movement. Another type of results depicted as the area delineated by polygon shows (movement area in Figure 7) the perception of rhino movement similar to the concept of movement within ‘home range’. Main basis for this choice was the frequent encounter with the rhino in these areas during the everyday activity of the participants.

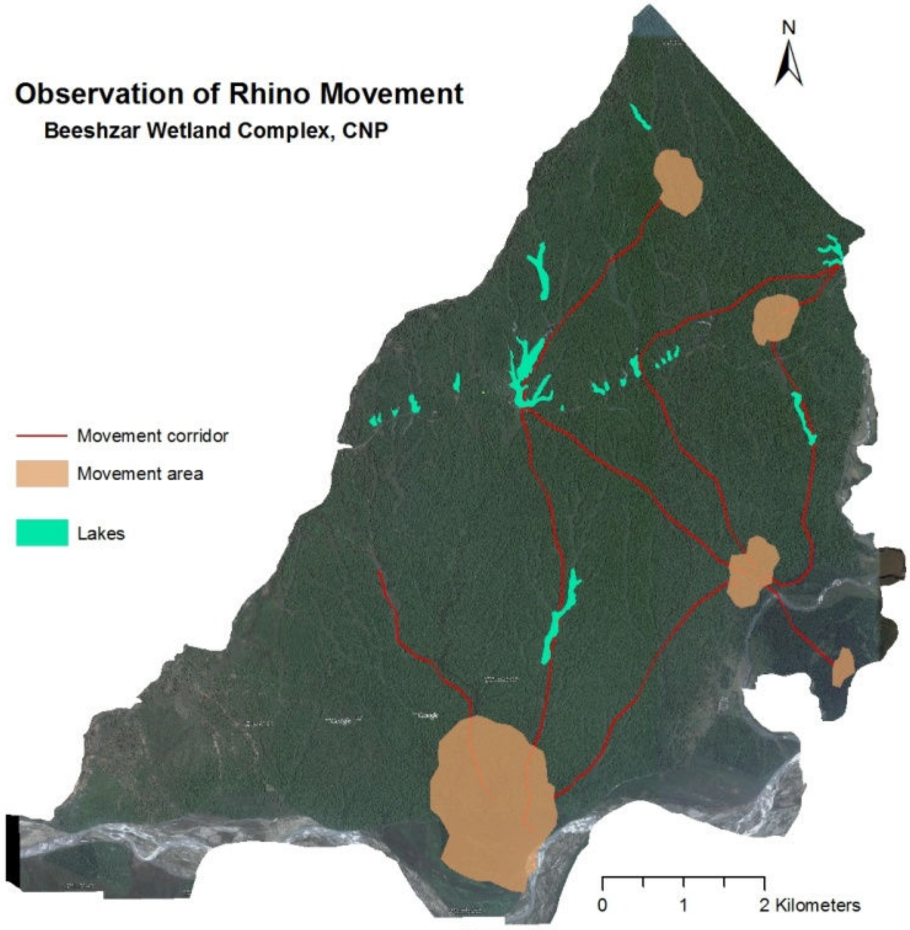

Figure 7: Geographic representation of rhino movement (*source: field work as part of Community GIS training, 26-29 January 2008; background image-Google Earth*)

Furthermore, conceptualization of rhino movement was also explained with reference to daily and seasonal movement pattern. It was explained that, daily movement occurs within short distance in search of food and water. Seasonal movement pattern is associated with the seasonal habitat change in the study area. Main essence for capturing this knowledge is to explore the varied way of the conceptualization of wildlife movement and their possible representation in GIS

4.3.2 Habitat change

It is observed that the local understanding of the habitat change is related with the changes that occurred in the existing land use/land use of the CNP. Five major habitat types, namely forest area, grassland, wetlands, river and riverine grassland riverine are associated with the land cover of the study area (see Figure 5). Perception of habitat change is also found in terms of seasonal and permanent change scenario. Seasonal change is specifically associated with grassland and wetland habitat. Most of the lakes in the Northern part of BWC dries out during the dry season. On the other hand, most of the riverine grassland during the rainy season gets inundated. Permanent changes are related with all possible change or disappearance of particular habitats caused by human or environmental phenomena. Change of forest habitat into agricultural area is an example of human induced permanent habitat change. Similarly, change of forest area into riverine grassland is a permanent change caused by river bank cutting.

The temporal reference of the perception of seasonal and permanent habitat change is found in terms of seasonal and yearly calendar. Habitat change is also examined by using the different time series Google imagery. However human conceptualization of seasonal and permanent change is difficult to visualize in the same way it is presented in satellite imagery. Figure 8 and Figure present an overview of the seasonal and permanent habitat change in terms of conceptual spatial representation respectively. Conceptual representation indicates the abstraction of the habitat change scenario with respect to observation of the reoccurring events that participate in seasonal and permanent habitat change process. On the other hand, spatial representation implies the snapshot view captured in satellite imagery at the two ends of the observation span.

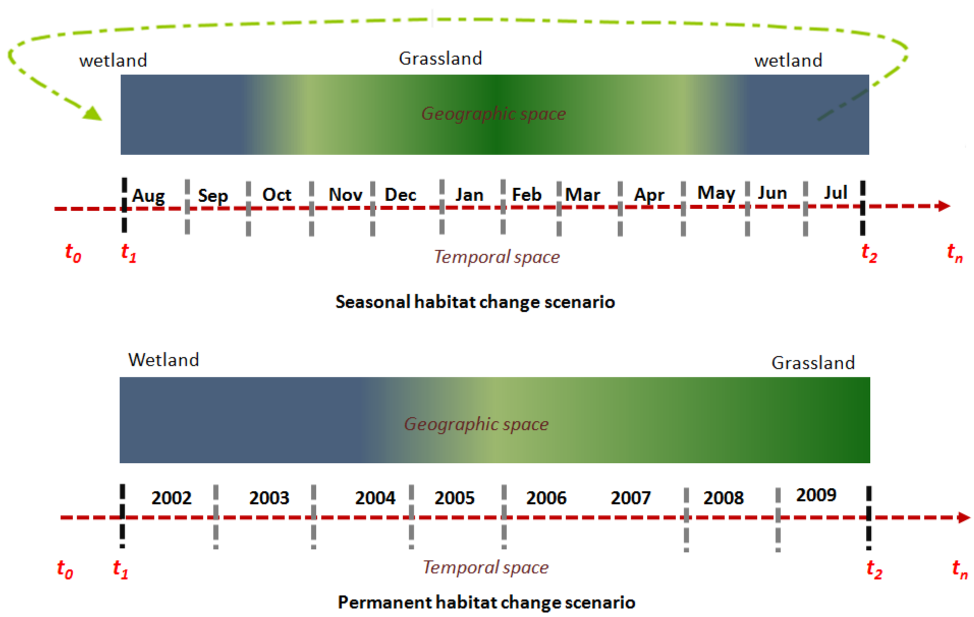

Figure 8: Conceptual representation of habitat change scenario

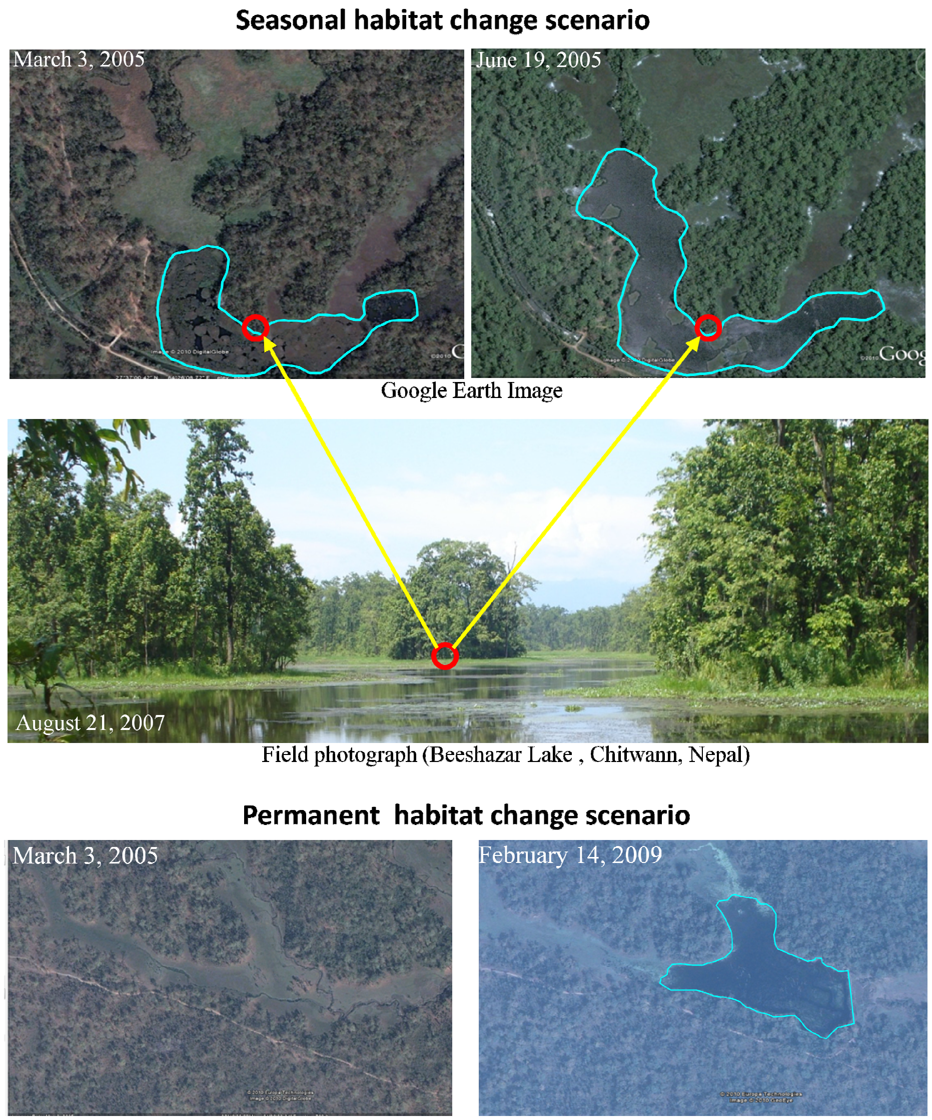

Figure 9: Spatial representation of habitat change scenario

4.3.3 Spatial reasoning for conservation planning

Commonsense spatial reasoning presented in this section aims to highlight the way local people make use of their spatial knowledge during the various conservation planning. Currently, rhino conservation is one of the major community concerns in the CNP. Habitat protection activities (eg. tree planting, river bank protection, construction of earthen dam in lakes, control for the excess extraction of forest products), development of tourism infrastructure in the national and buffer zone (development of trail for jungle safari, construction of view tower, night stay tower) are some activities that require substantial spatial knowledge to make a decision for conservation planning. Such spatial knowledge comprises their accumulated knowledge and understanding about the wildlife movement, habitat changes, human disturbance and natural environment. Spatial knowledge about conservation phenomena and its implication for the spatial reasoning during the conservation planning are highlighted in the examples below:

Example 1: How do the local community do reasoning to understand the disturbance on Rhino movement caused by elephant safari in BWC?

Elephant safari is one of the famous tourism services in the CNP which provide an opportunity for rhino sightseeing (Figure 10). The local community expressed that increased number of elephant safari has disturbed the rhino movement in the BWC. This reasoning was made based on the people's experience that the time required for elephant safari (jungle safari) to see a rhino is getting longer than before. In the past, they do not recall incidences where they could not find the rhino during elephant safaris. Now a days, there is an increase frequency of elephant safaris in BWC and they often return without sighting any rhinos. Although they do not have the standard method for keeping record of time interval and frequencies of elephant safari several, reasoning have been made based on commonsense knowledge gained through everyday experience *(source: discussion with forest guard during the map reading training)*.

Figure10: Elephant safari for rhino sightseeing in CNP *(source: http://himalayastrek.com/chitwan_national_park.php*)

Example 2: How do the local community do reasoning to identify the lakes that require a construction of earthen dam to hold water during the dry season?

Construction of earthen dams in the outlet of lakes is a conservation effort of local community for protecting rhino habitat. Since few years local people have been observing the early drying of lakes in the northern parts (upper part of the map in

Figure 7) of the BWC. Because of this, movement of rhino in northern part is decreasing during the dry season. Local people agreed to construct an earthen dam in the outlet of lakes to hold water for longer period or until the end of dry season. One of the major challenges for them was to identify the lakes that need to be protected at first priority. Although local community have understood that the lake is shrinking, it was difficult for them to compare the variation of the shrinking rate in different lakes *(source: discussion with tourist guide and member of buffer zone management committee during the Community GIS training).*

These are only some of many examples about how the local people use the commonsense spatial knowledge about space and time and how they infer new knowledge to understand conservation scenarios. It was observed that the spatial reasoning about conservation scenarios based on everyday experience is intuitive for the local community and, it is difficult to capture and describe explicitly as they understood and perceived. The subsequent sections attempt to provide the formal structuring and representation of the aforementioned commonsense knowledge and spatial reasoning about conservation scenario based on description logic and web ontology language (OWL).

5. DESIGNING CONCEPTUAL ONTOLOGY

This section corresponds with the second objective of the study. The development of 'Conservation GIS Ontology' is accomplished by dividing it into conceptual ontology and logical ontology. The process for designing conceptual ontology comprises of three major tasks: requirement for ontology; source knowledge capture and knowledge glossary terms; and formal structuring.

5.1 Requirement for ontology

The requirement of this ontology is to explore the semantic of the spatial information about conservation perceived and contributed by non-expert conservationists.

5.1.1 Motivation for building ontology

The main propose for building the 'Conservation GIS Ontology' is to conceptualize the non-expert conservationist's spatial knowledge about wildlife and habitat conservation with the consideration of saptio-temporal dimension. This will enrich the usability of geographic information related to the conservation domain contributed by 'VGI' and 'corwdsourcing'.

5.1.2 Scope of the ontology

The scope of the ontology means the area of knowledge the ontology will cover (Kovacs et al., 2006). The knowledge presented in this study is primarily based on the conservation scenarios discussed in section 4. Emphasis is given to elicit how the local people understand the conservation phenomena and changes occurred in various spatial-temporal scale. The main concern for building Conservation GIS Ontology is to conceptualize the everyday experience about conservation phenomena perceived by non-expert conservationists. Granularity of the spatial and thematic component of this ontology is related with the 'landscape'[9] perspective of CNP and does not necessarily cover all the regional, national and global conservation issues. Biodiversity resource and conservation scenarios are presented in the context of local people's understanding rather than the taxonomy of species existing in scientific arena. In this milieu, the specification of the proposed 'Conservation GIS Ontology' is presented in table 2.

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[9] Landscape is a large container of different processes that interact with each other to create the observed complexity (Farina, 2010).

Item		Specification
Domain	Related field	• Biodiversity conservation, GIS.
	Knowledge covered	• Commonsense spatial knowledge of conservation phenomena.
Purpose	Main purpose	• Conceptualization and formal representation of commonsense spatial knowledge about conservation in GIS.
	Intended uses	• Integration of VGI, crowdsourcing and non-expert spatial knowledge related to conservation with GIS. • To design new workflow and analysis architecture in GIS application to mimic the human conceptualization
Scope	Key concepts	• Conservation, Geographic representation, Temporal representation and Spatiotemporal particular
	Core concepts terms	• Wildlife mobility, habitat change , Human activities, Disaster phenomena, Institutional policy, Geographic features type, Geographic location, Temporal entity, Endurant, Pedurant, Quality.
Level of Formality	Conceptual Ontology	• Semi-formal; Description Logic.
	Logical ontology	• Formal- OWL language.
Granularity	Spatial	• The conservation scenario in the context of Chitwan National Park in Nepal.
	Thematic	• Conservation scenario and their spatio-temporal change.
Source of Knowledge	Commonsense knowledge	• Conservation narratives from local community, knowledge of non-expert conservationist, literatures.
	GIS data layers	• Satellite imagery, topographic digital layers.

Table 2: Requirement specification of ‘Conservation GIS Ontology’

5.1.3 Completeness and consistency questions

One of the most important tasks when building a new ontology is to determine the things that are in the domain to be modeled (Masolo et al., 2002). Completeness and consistency questions basically ask about the key objects and relationship between them that are essential to define the domain knowledge (Kovacs et al., 2006). The main purpose for asking the completeness and consistency questions in the beginning of ontology development phase is to ensure the knowledge and the core concepts remains focused on the scope and purpose of the ontology. In this study, core concepts related to conservation and their geographic and temporal representations for describing the conservation scenario are the key 'objects'. Some competency related questions essential to ensure the concepts of domain knowledge are:

- What are the main concepts that describe the wildlife and habitat conservation in CNP?
- What are the conservation scenarios that have multiple geographic representations?
- What are the phenomena that characterize the process of habitat change scenario?
- What are the relationship between conservation, geographic representation and temporal representation that describes the spatiotemporal change of wildlife population and habitat?

5.2 Source knowledge capture and knowledge glossary

The first task in order to develop ontology is to interpret the key terms precisely, and characterize their relationship to real world (Bennett, 2010). The essence for describing the source knowledge and knowledge glossary is to populate the content of ontology that includes the description of the main concepts and satisfy the purpose and scope of the ontology. Source knowledge and knowledge glossary required to define the 'Conservation GIS Ontology' are presented in two parts: concept terms and relationship terms.

5.2.1 Concept terms

Concepts can be abstract or concrete, elementary or composite, real or fictitious, description of a task, function, action, strategy, reasoning process, and so on (Gomez-Perez and Corcho, 2002).Concept terms aims to capture the main concepts that are essential to conceptualize the domain ontology. Based on the intended meaning, main concept terms are classified as core concepts and secondary concepts. Core concepts are those terms (usually nouns) that are central to describe the domain. Secondary concepts are required to fully describe the core concepts and satisfy the purpose of the ontology (Kovacs et al., 2006). For example, wildlife movement and wildlife observation are the core concepts and wildlife activities such as grazing, running etc. are the secondary concepts. Based on the non-expert conservationists' knowledge and the conservation scenario, the core concepts that are essential to define the 'Conservation GIS Ontology' are grouped into four parts: conservation; geographic representation; temporal representation and spatio-temporal particular.

5.2.1.1 Concepts related to conservation

Concepts terms related to the conservation comprises wildlife, habitat, human activities, environmental phenomenon, disaster phenomena and institutional policy. These concept terms are further populated by sub concepts. Eliciting the concept terms about conservation are carried out with the norm of 'geographic category' (Mark and Smith, 2001). With this norm, each family of commonsense knowledge categories is organized hierarchically. The general categories are in the top of the hierarchy and more specific categories appear as branches (Figure 11). Descriptions of each concept terms are made with reference to the commonsense knowledge perspective (detailed descriptions are provided in Appendix- 2).

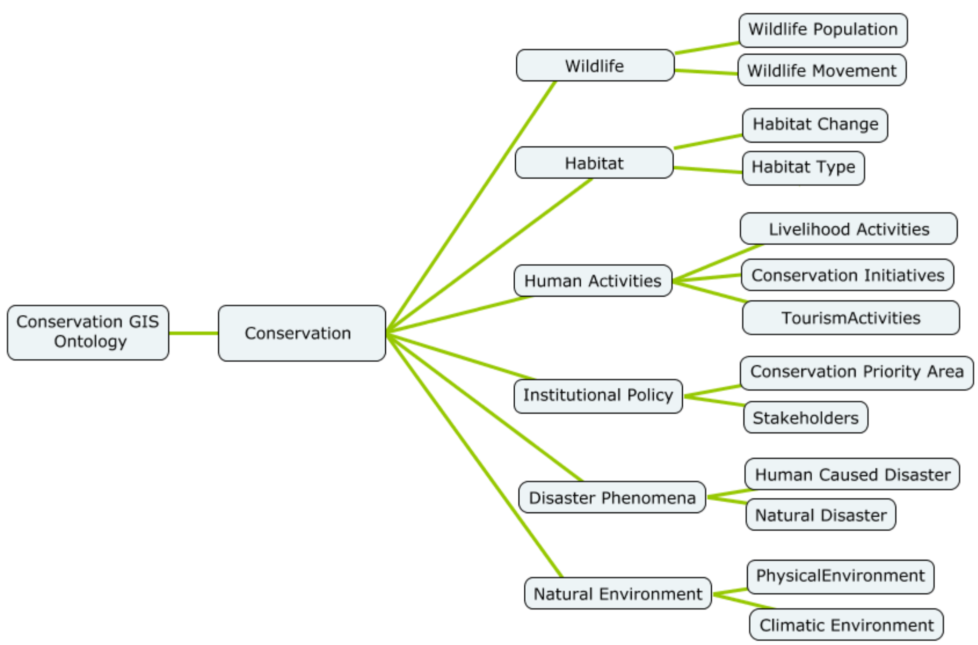

Figure 11: Concept terms related to conservation

5.2.1.2 Concepts related to geographic representation

The main purpose for providing the concepts related to geographic representation is to embrace the various spatial concepts that characterize the conservation scenario. In this regard, concept terms of geographic representation must cover varied human conceptualization of conservation ranging from abstract to basic geometric footprints. Elicitation of the spatial concepts is carried out considering the perspective of 'object vs. field view', 'absolute vs. relative location' and primitive geometry of geographic information in GIS (Frank, 1997; Smith and Varzi, 1997) ontology of geographic object (Casati, Smith, and Varzi, 1998; Mark and Smith, 2001; Abdelmoty et al. 2005;Fonseca, Câmara and Monterio, 2006; and Wang et al., 2007). This choice is made by assimilating the notion of 'ontology of space' (Frank, 1997) to describe the spatial concept about conservation phenomena. Figure 12 provides an overview of the concept terms about geographic information essential to define the proposed domain ontology (detailed descriptions are provided in Apendix-3).

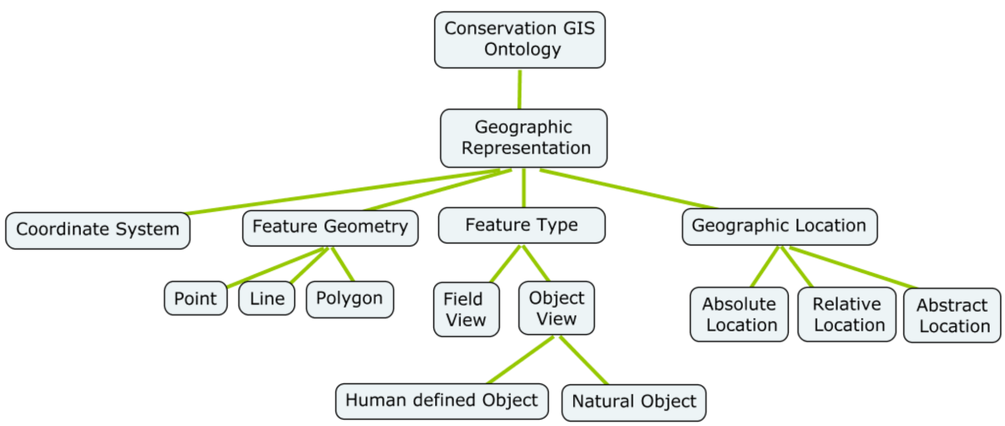

Figure 12: Concept terms of geographic representation (*adopted and modified from Casati, Smith and Varzi, 1998; Abdelmoty et al. 2005; and Fonseca, Câmara, and Monterio, 2006*)

5.2.1.3 Concepts related to temporal representation

Concepts related to the temporal representation aims to provide the temporal reference for the conservation scenario. Concept terms for temporal representation are adopted from the 'time ontology'[10]. Figure 13 shows the terms essential to represent the temporal dimension of conservation phenomenon in this research context (detailed descriptions are provided in Appendix-4).

[10] http://www.w3.org/TR/owl-time/

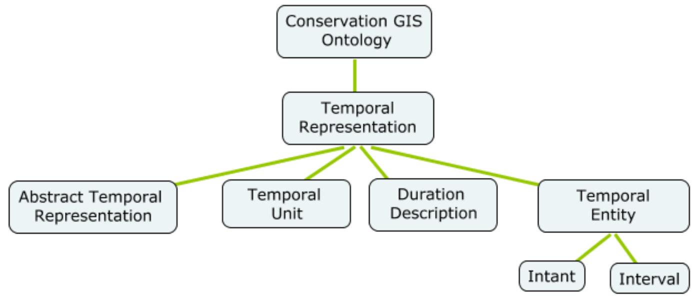

Figure 13: Concept terms of temporal representation (*adopted from* *http://www.w3.org/TR/owl-time/*)

5.2.1.4 Concept terms related to spatio-temporal particular

Elicitations of the terms for describing the spatio-temporal particular about the 'conservation' are adopted from DOLCE (Descriptive ontology for Linguistic and Cognitive Engineering)[11]. Although DOLCE is a top level ontology (Masolo et al., 2002), the purpose for adopting the concept terms from DOLCE is to enhance the quality of domain ontology by providing its foundation on upper level ontology (Klien and Probst, 2005). The notion of the SNAP and SPAN by (Grenon and Smith, 2004) in BFO (Basic Formal Ontology)[12] are also considered to establish the relationship between the concepts about conservation phenomena and spatiotemporal change. Figure 14 presents an overview of the concepts for describing the spatiotemporal change of conservation phenomena (detailed descriptions are provided in Appendix-5).

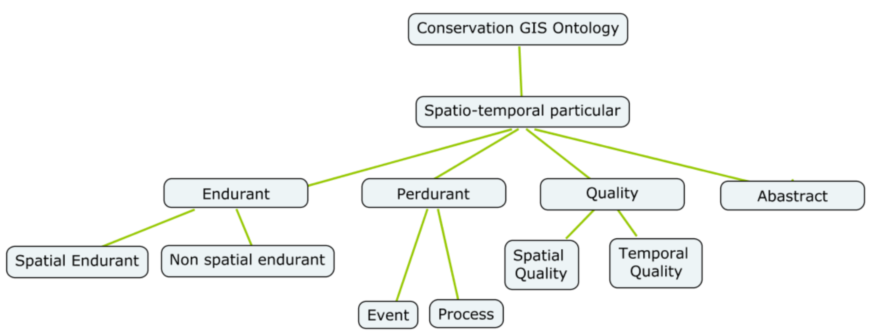

Figure 14: Concept terms of spatio-temporal particular (adopted from DOLCE ontology)

[11] http://www.loa-cnr.it/DOLCE.html
[12] http://www.ifomis.org/bfo

5.2.2 Relationship terms

Relationship term connects two or more concept terms to describe the meaning of the ontology. The relationship between the concept terms can be characterized as hierarchical and non- hierarchical relations. Hierarchical relations depict the mereological relationship between the concept terms and is often denoted by ‘is a’ relation. Non-hierarchical relation describes the defined meaning of the relationship between concept terms using the association and equivalency property (Deliiska, 2007). Figure 15 presents an overview of the hierarchical and non hierarchical relationship between the core concept terms of the Conservation GIS Ontology. To conceptualize the domain knowledge, the main aim of this section is to describe the relationship terms associated with the non-hierarchical relationship.

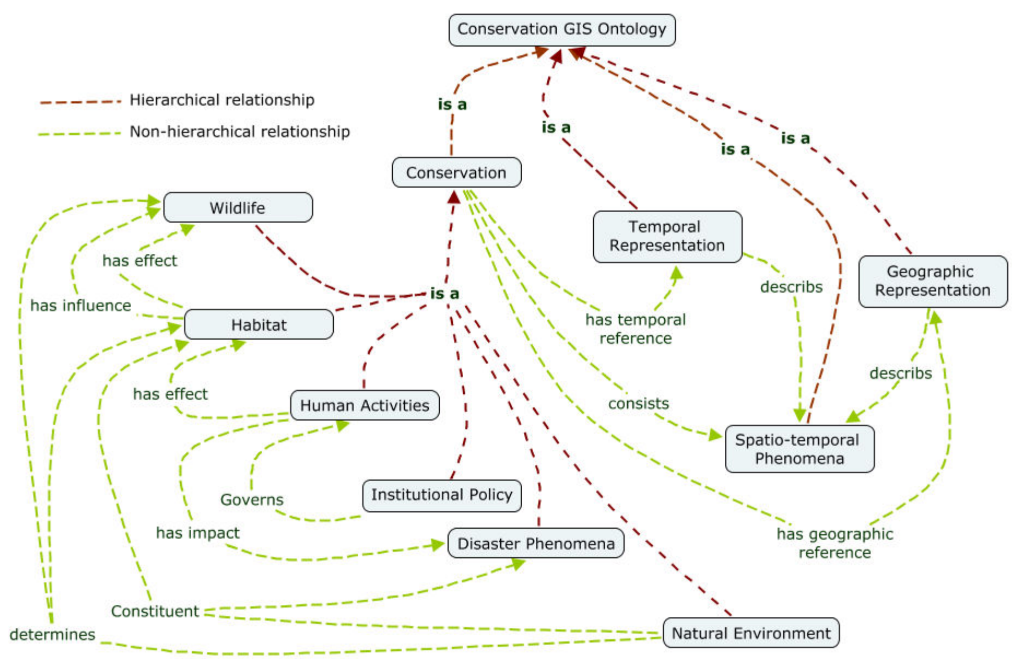

Figure 15: Hierarchical and non-hierarchical relationship between concepts

In conceptual ontology, the relationship terms are part of the sentence that contains verbs and may express movement in space, action, and occurrence and so on (Kovacs et al., 2006). For example, in the sentence ‘human activities influences wildlife movement’, the term ‘influence’ is the relationship terms and connect the concept terms ‘wildlife movement’ and ‘human activities. Relationship terms and their characteristic applied for constructing Conservation GIS Ontology are presented in Appendix-6.

5.3 Formal structuring

The main task in this phase of conceptual ontology development is to describe the concept and relationship terms in a natural language sentence. A formal structuring of the aforementioned concepts are presented in two parts: open world vs. close world assumption and relationship rule

5.3.1 Open world vs. close world assumption

There are two ways of formal structuring the domain knowledge. One is called Closed World Assumption (CWA) and another is Open World Assumption (OWA). The close world reasoning states that anything that cannot be found in a knowledge base is false. In contrary, open world reasoning states that anything might be true unless it is explicitly stated to be false or can be proven to be false (Kovacs et al., 2006). In OWL language, OWA is called 'existential restriction' and denoted by 'some' ($\sqsupset$). Similarly CWA is called 'universal restriction' and denoted by 'only' ($\forall$) (Horridge et al., 2009).

Since the knowledge captured in this study does not account for the complete domain knowledge, formal structuring is described using OWA. In some cases, such as relationships between the 'Conservation Phenomena' with 'Feature Geometry' close world assumption CWA is described along with OWA.

For example, we have captured the knowledge that wildlife movement is influenced by human activities and formal structuring based on the OWA and CWA can be expressed as:

Wildlife movement is influenced by some tourism activities
Wildlife movement is influenced by only tourism activities

The first sentence is structured based OWA and implies that there is also possibility of other human activities which may or may not influence the wildlife movement. The second sentence is structured using CWA and implies that wildlife movement cannot be influenced by human activities other than tourism activities. In this case choosing the CWA will not represents the knowledge in the way it was captured and conceptualized. Similarly, if we do not say that wildlife movement can be influenced by human activities then, based on CWA, the interpretation is that wildlife movement cannot be influenced by human activities.

5.3.2 Relationship rules

Relationship rules in the formal structure of ontology dealt with the characteristics of the relationship term. Basic relationship rules applied in OWL language are: functional, transitive, symmetric, asymmetric, reflexive and irreflexive (Kovacs et al., 2006). This study only make the use of functional, transitive, symmetry and asymmetry.

5.3.2.1 Functional

"If a property is functional then,

For a given individual, there can be at most one individual that is related to the individual via the property."

The relationship term 'has_Geographic_Reference' and 'has_Temporal_Representation' are defined as functional property with the concept term 'Geographic Representation' and 'Temporal Representation' respectively. Expressions of this statement in description logic are:

Relationship term: has_Geographic_Reference; has_Temporal Reference
Conservation_Phenomena has_Geographic_Reference some Geographic_Representation
Conservation_Phenomena has_Temporal_Reference some Temporal_Representation
This implies that if a conservation phenomenon is related with Geographic Representation, then there must be one type of geographic representation associated with conservation phenomena.

5.3.2.2 Transitive

"If a relationship term 'R' relates concept terms 'a' to 'b' and 'b' to 'c' then, 'R' also relates 'a' to 'c'"

Transitive rule is assigned to represent the conceptualization how people infer new knowledge by associating various relationship among conservation phenomena. For example, human activates such as cattle grazing is one of the cause of habitat change. On the other hand, habitat change is one of the causes of wildlife movement. And hence, cattle grazing can also be the cause wildlife movement. But, in formal language, these statements do not imply that a cattle grazing is also one of drivers for disturbing wildlife movement. An example of transitive property assigned in this ontology is provided in following expression:

Relationship term: has effect (Transitive rule)

a) Human_Activities has_Effect some Habitat_Change
b) Habitat_Change has_Effect some Wildlife_Mobility,
Then,
Human_Activities has_Effect some Wildlife_Mobility

5.3.2.3 Symmetry

In Symmetry rule, If a relationship term 'R' relates concept terms 'a' to 'b' then, 'R' also relates 'b' to 'a'

There are some human activities that are directly related to cause some disaster phenomena. As a result, such activities itself get affected by disaster phenomena.

Relationship term: hasImpact (symmetry)
If, Human_Activities has_Impact some Human Caused _Disaster
Then, Human Caused _Disaster has_Impact some Human_Activities

5.3.2.4 Asymmetric

If a relationship term 'R' relates concept terms 'a' to 'b' then, 'R' cannot relates 'b' to 'a'

This rule is applied between habitat change and wildlife mobility to represent the knowledge that habitat change can cause the change on wildlife mobility but wildlife mobility itself do not have any relation to cause habitat change. We express this knowledge in formal structuring as

Relationship term: HasInfluence(asymmetric)

If, Habitat_Change has_Influence some Wildlife_Mobility
Then,
Wildlife_Mobility has_Influence some (not Habitat_Change)

6. DEVELPING LOGICAL ONTOLOGY

The process for converting the conceptual ontology into logical ontology is also known as ontology engineering. In this section, 'developing logical ontology' refers to the ontology engineering task that aims to populate OWL ontology through the formal representation of domain knowledge. There are several ontology development toolkits which provide an integrated environment to build and edit ontology and check for errors and inconsistencies

In this study the task of ontology development is accomplished by using Protégé 4.1 beta[13] ontology editor. 'Protégé OWL Tutorial'[14] available with the example for authoring 'Pizza Ontology' is used as a reference material. The remaining part of this section describes the step-by-step process for authoring Conservation GIS Ontology encoded in Web Ontology Language (OWL2).

6.1. Terminology and relationship

Before starting to construct ontology in computational environment, it is necessary to understand the basic terminologies adapted by the chosen ontology editor and their relationship with conceptual ontology. Figure 16 presents the relationship between conceptual ontology and logical ontology with reference to OWL used in Protégé 4.1 beta. There are three version of OWL namely 'OWL Lite', 'OWL DL' and 'OWL Full' (see section 2.3.5.1). This study makes use of OWL DL functionality to allow maximum expressiveness in the logical ontology.

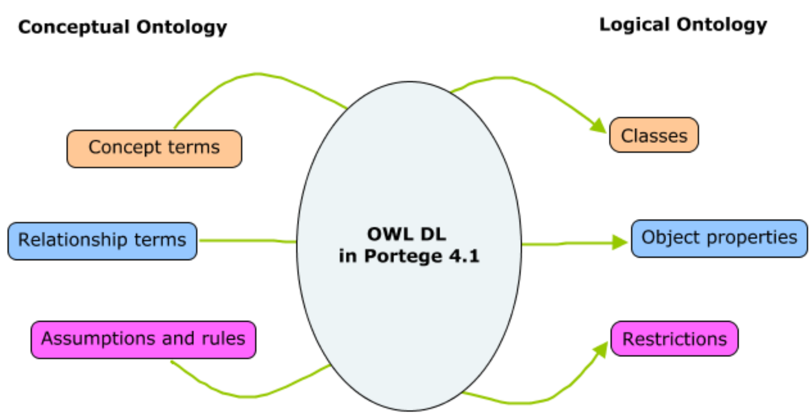

Figure 16: Terminology and relationship between logical and conceptual ontology

13 http://protege.stanford.edu/
14 http://owl.cs.manchester.ac.uk/tutorials/protegeowltutorial/

Figure 16 indicates that classes in OWL are used to refer the concepts of domain knowledge. OWL classes are described using formal (mathematical) description that states precisely the requirements for membership of the classes. Classes are organized into a superclass - subclasses hierarchy, which is also known as taxonomy. Hence, these superclass-subclass relationships can be computed automatically by using Reasoner. Similarly, property in OWL refers to the relationship terms of conceptual ontology. OWL properties are a binary relation which links two classes or individual together. Restriction in OWL refers to the assumption and relationship rules expressed in conceptual ontology (Horridge et al., 2009).

6.2 OWL namespace and general conventions

The first step for creating new OWL ontology is to create a new ontology file using ontology editor. For this, it is required to have a namespace for ontology. Namesapce is basically a way to provide a Unique Resource Identifiers (URI) for the ontology and its class and properties so that it can be referenced on the web (Goodwin, 2007). These provide a means to unambiguously interpret identifiers and make the rest of the ontology presentation more readable.

Although there is no mandatory naming convention in OWL, Horridge et al. (2009) propose to start classes with uppercase letter and properties with lower case letter. Subsequent words for both classes and properties begin with uppercase letter in both and words can be separated using underscore. For example "Wildlife_Movement" indicates the classes and "has_Geographic_Reference" indicates the property.

6.3 Building OWL classes

After creating the namespace, the next step is to create the classes, subclasses and their hierarchy. Classes are the main building blocks of OWL ontology. In 'Protégé 4.1 beta', the empty ontology is called 'Thing'. All the classes are created as subclasses of 'Thing' (Horridge et al., 2009). Conservation GIS ontology is created as subclasses of 'Thing'. All the concepts are arranged in a classes and subclasses of four main domain concepts: Conservation phenomena, geographic representation, temporal representation and spatiotemporal phenomena. The classes and subclasses hierarchy of Conservation GIS Ontology is presented in Figure 17.

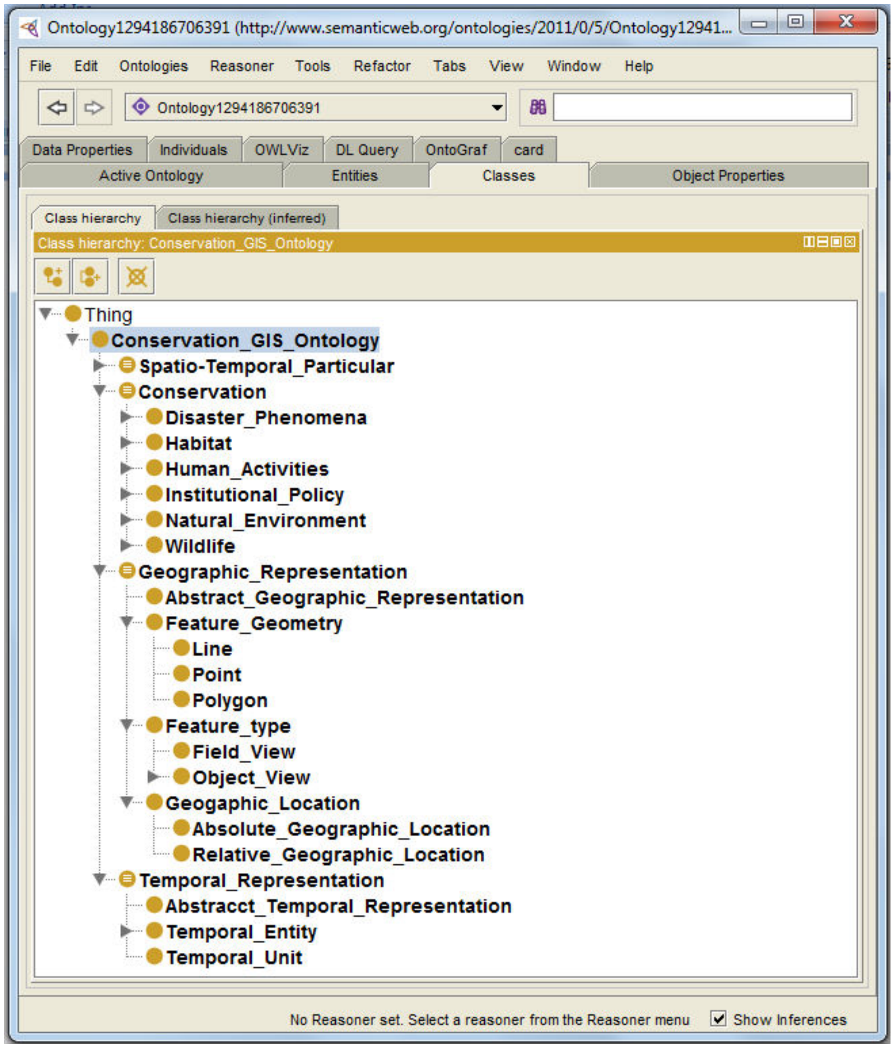

Figure 17: Class hierarchy of 'Conservation GIS Ontology' in Protégé 4.1

After creating the OWL class, next task is to specify disjoint classes in the hierarchy. OWL classes are assumed to 'overlap'. Therefore, an individual can be assumed to be member of more than one class. But in some real world cases an individual cannot be a member of more than one class at the same time. In such situations it is necessary to separate the group of classes using disjoint axioms. In description logics two classes are considered as disjoint 'iff' their taxonomic overlap, i.e. the set of common individuals, must be empty (Völker, Vrandečić and Sure, 2007). In this ontology only the subclasses in the lower hierarchy are considered as disjoint classes. Some of classes at top hierarchy are defined with 'the necessary and sufficient condition' and hence are not considered as disjoint class (Some codes of OWL classes are provided in Appendix-7).

6.4 OWL properties

There are two types of OWL property: Object properties and data properties. Object properties describe the relationship between two individuals whereas data properties describe the relationship between individual and data value. Each Property may have inverse property which is used to infer inverse relationship. Inverse property also provides the completeness for the relationship between individuals (Horridge et al., 2009). All the relationship terms discussed in section 4.3.1 are arranged as object property and respective inverse. Figure 18 presents an overview of object property and their inverse property essential for defining Conservation GIS Ontology.

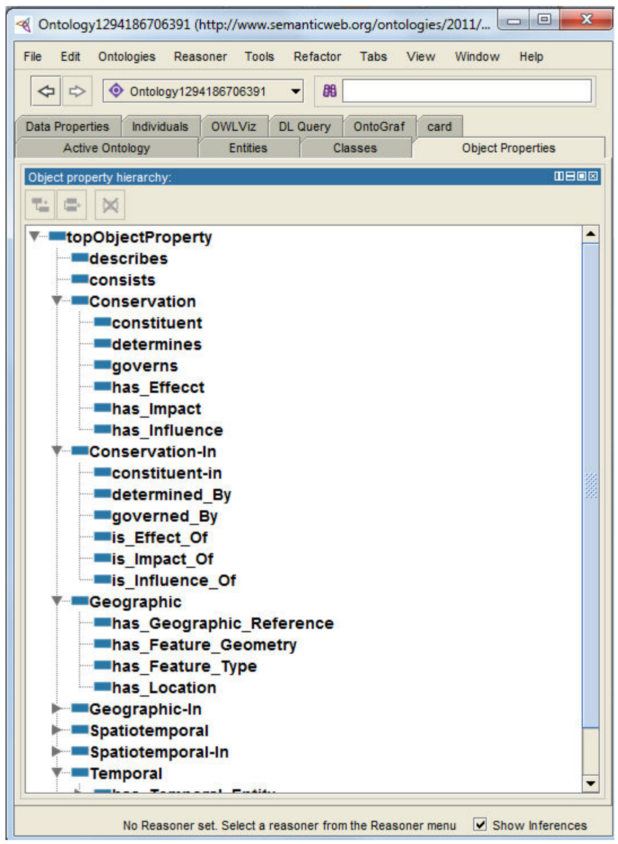

Figure 18: Object property 'Conservation GIS Ontology' in Protégé 4.1

6.4.1 Property characteristics

As discussed in section 5.3.2 some of the domain knowledge are conceptualized based on functional, transitivity, symmetry and irreflexive. In OWL, such rules are called characteristics of the object properties. These rules are assigned to respective property using the object property characteristic facility available in Protégé 4.1.

6.4.2 Domain and range

Defining the domain and range in ontology has global implications which can be further used as axioms for reasoning. Defining the domain allows to limit the statements in its subject where-as assigning range limit the meaning within the objects. Based on the provided domain and range of object property, a Reasoner can detect mistakes and inconsistencies or the represented knowledge (Horridge et al., 2009). Domain and range of the each object property are assigned according to the relationship term description (Attachment 6). Figure 19 presents an example of domain and range of property ‘has_Feature_Geometry’ in Protégé 4.1 domain and range view window.

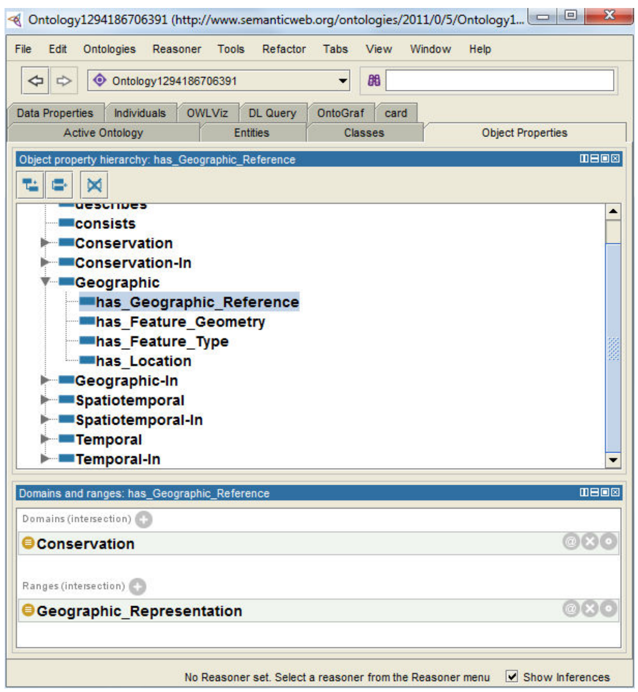

Figure 19: Domain and range of property “has_Feature_Geometry”

6.5 Describing and defining classes

Class description and definition tasks are carried out in two different ways: property restriction; and necessary and sufficient condition.

6.5.1 Property restriction

In this phase, non-hierarchical relationships between classes and subclasses are defined using object property and restrictions. A restriction describes a class of individuals based on the relationship that member of class participates in. Although OWL provides three types of property restrictions: quantifier restrictions; cardinality; and has value, this study only makes use of quantifier restriction. Quantifier restriction is further classified into existential and universal restriction. These two restrictions are based on the Open world Assumption and Close World Assumption respectively and in Protégé 4.1 the terms 'Only' and 'Some' are used to represent them (Horridge et al., 2009). Figure 20 shows an example for property restriction assigned to define a class 'habitat'

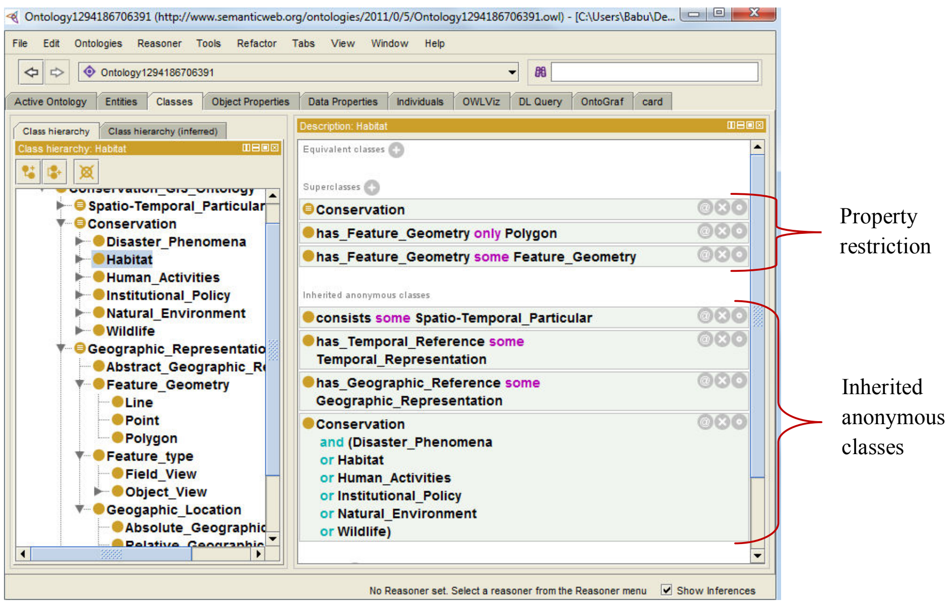

Figure 20: Description of a class 'habitat' by using property restriction

6.2.2 Necessary and sufficient condition

All the classes described using property restriction only implies the necessary condition for an individual to be member of that class. Necessary condition characterized the classes as - 'if something is a member of this class, then it is necessary to fulfill these conditions'. This statement is not always sufficient to say that 'if something fulfills these conditions then, it must be a member of this classes'. In Protégé 4.1, the necessary conditions are called super classes and the necessary and sufficient classes are called equivalent classes. Below is an example of necessary condition that is used to define seasonal habitat change.

Seasonal_Change constituent some Named_Habitat_Change (Grassland_To_Wetland or Wetland_ to_Grassland)

The above expression implies that habitat change from grassland to wetland and wetland to grassland describes the scenario of seasonal habitat change but does not imply to be the members of the defined relationship. To describe the seasonal habitat change scenario, the classes ‘Grassland_To_Wetland’ and ‘Wetland_ To_Grassland’ should be the member of the defined relationship. To describe this, the above expression needs to be converted into equivalent classes. Figure 21 shows the equivalent classes of seasonal habitat change in Protégé 4.1 class hierarchy window.

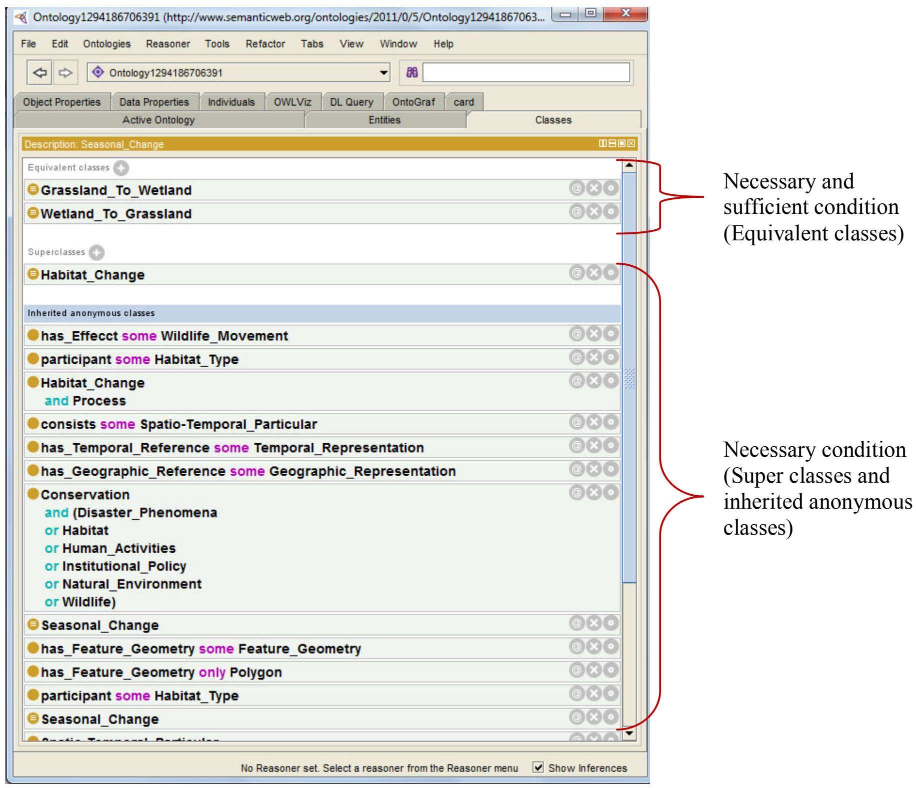

Figure 21: Necessary and sufficient condition for class ‘seasonal habitat change’

6.6 Ontology verification

Verification refers to the technical process that guarantees the correctness of ontology in associated software environment (Fernandez, A. Gomez-Perez and Juristo, 1997). The main purpose of the ontology verification in this is to confirm that the logical ontology development tasks discussed in earlier sections is technically correct to describe the domain knowledge.

In this study, ontology verification is made by checking the inconsistencies in ontology. For this purpose, inserted class hierarchy is classified by using Pellete reasoner[15] available in Protégé 4.1 beta. After classification, inferred class hierarchy is created by the reasoner. If a class has been found to be inconsistent, the classes in inferred hierarchy will be highlighted in red colour. Correction of such inconsistent class is examined by reviewing the defined property such as disjoint, domain and range. Figure 22 show the consistent class in both inserted hierarchy (left side) and inferred hierarchy (right side).

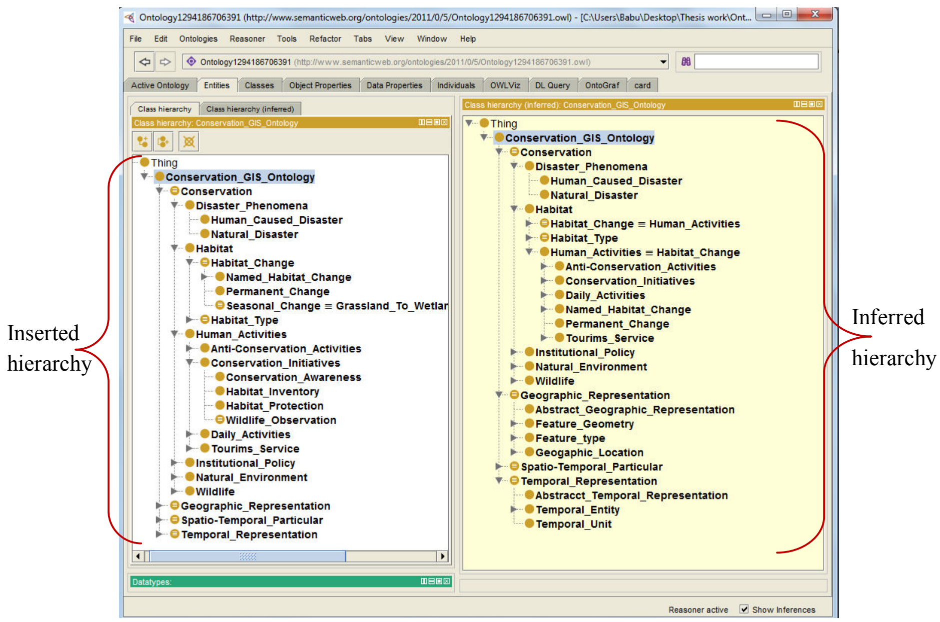

Figure 22: Inserted and inferred class hierarchy

6.7 Ontology documentation

There are no clearly defined guidelines on how to document ontology. In many cases the code of ontology and the natural language text attached to the formal definitions are considered to be the documentation of ontology (Fernandez, A. Gomez-Perez and Juristo, 1997). In this study, the ontology file of 'Conservation GIS Ontology' coded in OWL using Protégée 4.1 ontology editor is considered as the final documentation of the commonsense spatial knowledge and their formal representation. All the intended manning embodied with the concept terms and relationship terms to describe the domain knowledge are inserted in OWL as the annotation property.

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[15] http://www.w3.org/2001/sw/wiki/Pellet, http://clarkparsia.com/pellet

7. EVALUATION

The main accomplishment of this study is the preparation of 'Conservation GIS Ontology' comprising commonsense spatial knowledge about the conservation. This section discusses the evaluation of this ontology and some strengths and limitations.

7.1 OWL Ontology evaluation

Ontology evaluation means to carry out a technical judgment of the ontology (Fernandez, Gomez-Perez and Juristo, 1997). Basically there are two methods for evaluating OWL ontology: extrinsic and intrinsic. Extrinsic evaluation method concerns external information, expert opinion or a particular task that defies the context. Intrinsic methods reflect the structural quality of the ontology which can be evaluated as a standalone body of domain knowledge. (Netzer et al., 2009). Due to the constraints of existent data related with conceptualized domain knowledge in this ontology, the choice of intrinsic approach is made to evaluate the 'Conservation GIS Ontology'. Regarding the intrinsic method, Gómez-Pérez (2004) pointed out two levels of ontology evaluation tasks: ontology verification and ontology validation. This section concerns only the validation task to evaluate the quality of the ontology.

The goal of ontology validation is to show that the world model is compliant with the formal models (Vrandecic, 2010). Gruninger and Fox (1995) have discussed about asking the competencies questions for the validation of ontology. Completeness measures whether the domain of interest is appropriately covered or not. For this purpose, a set of informal competencies questions that ontology is supposed to answer is required. For the evaluation purpose such informal competencies questions need to specify based on the formal structuring employed during ontology development phase. Competencies of the ontology are assessed by asking the several competencies questions to the OWL ontology. This task is facilitated by adopting the methods for OWL evaluation available in the ontology editor.

7.1.1 Requirements

Validation of OWL Ontology is carried out using OWL Reasoner and DL Query facility available in Protégé 4.1 Ontology Editor. OWL Reasoner is a tool that can perform reasoning tasks based on OWL. There are several OWL Reasoner available for Protégé OWL editor, this study makes use of Pellet. Pellet is a complete OWL-DL Reasoner which provides support for reasoning with individuals, user-defined data types and debugging support for ontologies (Sirin et al, 2007). The DL Query has a powerful and easy to use feature for searching a classified ontology[16]. Considering the core concept of the domain knowledge discussed in section 5, assessment of the competency of the OWL Ontology is examined by asking three distinct competencies questions.

Question 1: What are the phenomena that have effect on wildlife movement?

Question 2: what are the phenomena that describe the seasonal habitat change scenario?

Question 3: What are the conservation phenomena that have only point feature as geographic representation?

7.1.2. Execution

To answer these questions first of all it is necessary to understand how the domain knowledge is formalized in OWL ontology. Based on formal structuring and relationship rule (discussed in section 5.3.2.) aforementioned competency questions should be expressed as:

Q 1: has_Effecct some Wildlife_Movement

Q 2: Habitat_Change

Q 3: has_Feature_Geometry only Point

To get answer from OWL Ontology, using *Protégé 4.1.*, the following steps require to be executed.

- Run the Reasoner (Pellet)
- Type the above expression in DL Query window
- Defined the required level of results (eg. 'subclasses', equivalent classes)
- Execute the DL Query task

7.1.3 Results

Results for Q1

DL Query result (Figure 23) shows that Human_Aactivities´' and 'Habitat_Change' has some effect to wildlife movement. In this ontology *'has_Effect'* is characterized as 'transitivity' and used to describe the non-hierarchical relationship between 'Human_Activity' to Habitat-Change and Habitat_Change to Wildlife Movement'. Although the classes 'Human_Activity' and 'Wildlife_Movement' are not defined through

[16] http://protegewiki.stanford.edu/wiki/DL_Query

‘has_Effect’ property, because of the transitive relation the Reasoner is capable to infer this relationship via their relationship with class ‘Habitat_Change’

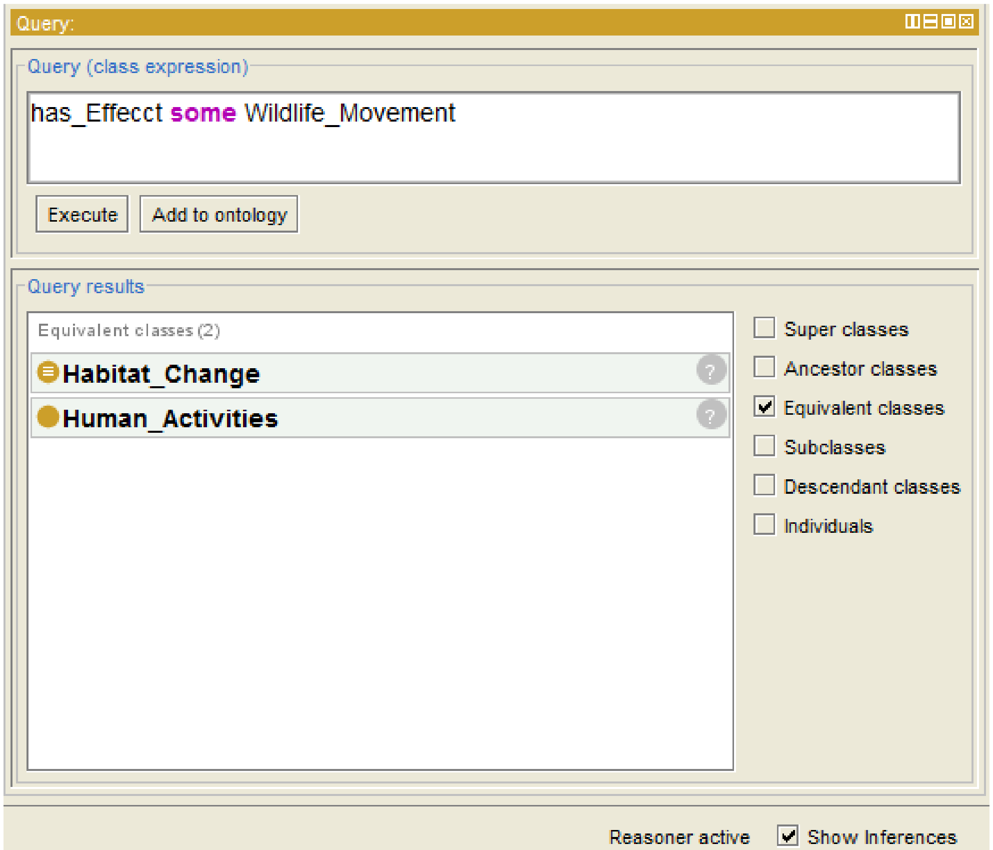

Figure 23: DL Query results of question no.

Results for Q2

This question asks about the individuals that describes the habitat change. Results presented in fugure 24 shows that the ‘Named_Habitat_Change’, ‘Permanent_Change’ and ‘Seasonal_Change’ are the individuals that describe the habitat change. In this ontology, these individuals have hierarchical relation ‘is a’ (hierarchical relation) with Habitat_Change (see Figure 14). Because of subsumption axiom, the Reasoner is capable to infer the new knowledge that describes the habitat change scenario.

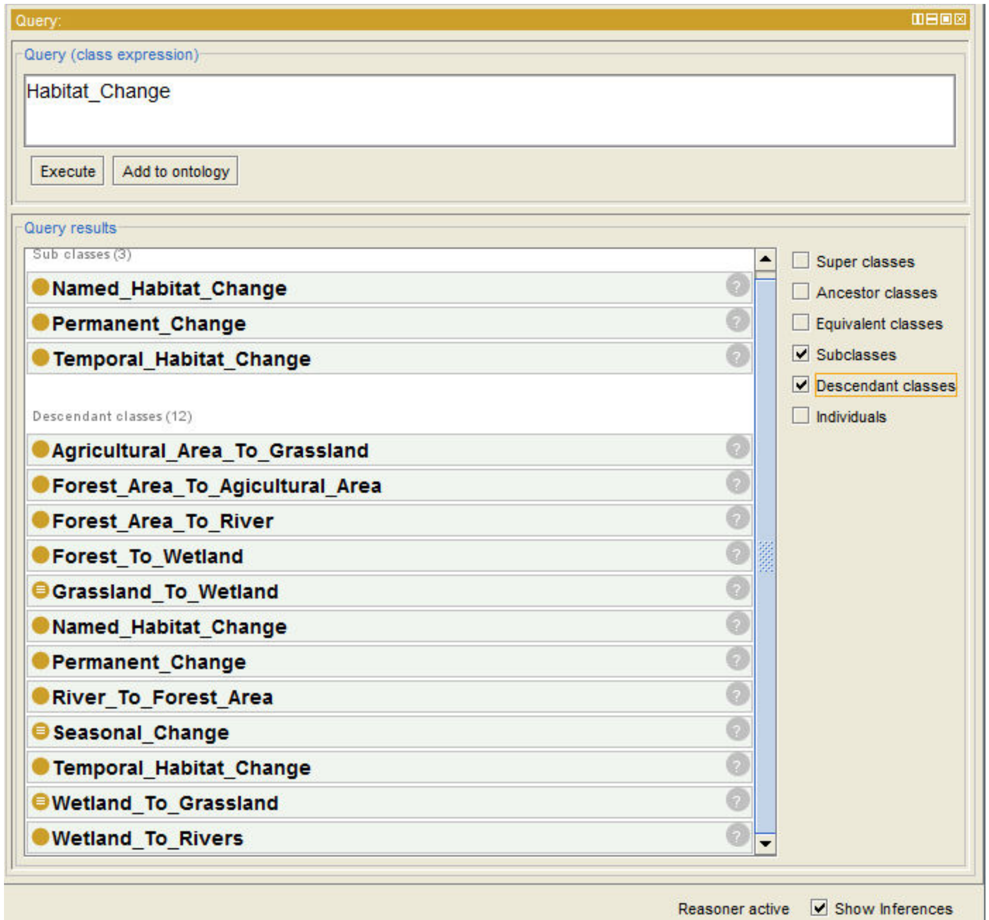

Figure 24: DL Query results of habitat change scenario

Results for Q3

To examine this competency question, first of all it is necessary to understand the open world and close world assumption in Description logic (see section 5. 3). Question is asking about the individuals of the class defined using universal restriction between ‘Conservation_Phenomena’ and Geographic_Representation’. Results presented in figure 25 shows that wildlife observation is the individual of the class defined by the universal property restriction. Although, wildlife observation may have other forms of geographic representation, in terms of feature geometry or footprint of the observation, it is restricted only with point feature. The ‘Reasoner’ is capable to distinguish the various restrictions assigned to define the domain knowledge in this ontology.

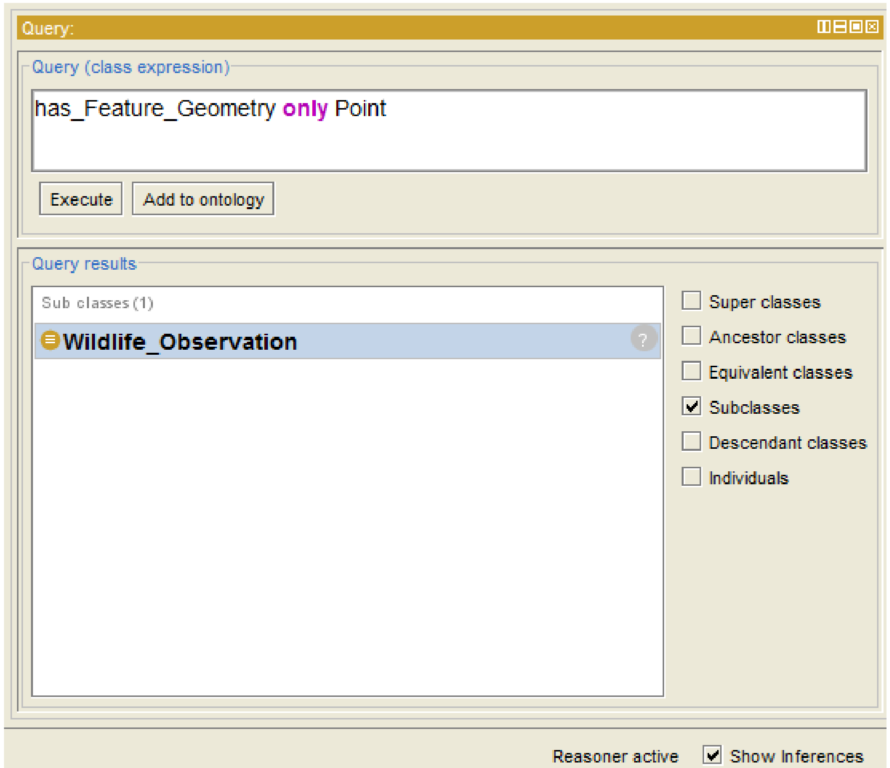

Figure 25: DL Query results of Q3

Although the competency questions examined in the above examples are only some indicative scenarios, it indicates that the knowledge conceptualized and represented in this ontology is in accordance with the formal language. Because of this, the 'Reasoner' is capable to perform reasoning on 'Conservation GIS Ontology' to infer new knowledge.

7.2 Limitation

One of the major constraints while performing the DL Query based intrinsic evaluation is its restriction in the vocabulary that exists inside the Ontology. To accommodate the more complex and varied knowledge, further improvements, updates and modification of this ontology is required. The task of ontology developments is an iterative and dynamic process and an ontology designed for first time are rarely close to perfection. The main reason behind this is that the reality is complex and human ability is limited to cope this (Stojanovic and Motik, 2002). This study is not an exception, rather confronted with several problems to delineate the crisp benchmark for eliciting the domain knowledge grounded on human conceptualization. Since the evaluation presented in aforementioned sections are carried out based on the intrinsic method, qualities of ontology only confirms the structure property. Quality of the ontology regarding usage scenarios are beyond the scope of the study.

8. SUMMARY, CONCLUSION AND FUTURE WORK

8.1 Summary

Exploration of commonsense spatial knowledge about conservation phenomena and ontology development are the two major accomplished tasks in this study. Summary of each task is presented with reference to underlying theoretical and methodological considerations.

8.1.1 Commonsense spatial knowledge: An alternative grounding for geospatial ontology

Exploration of commonsense spatial knowledge begins with an overview of the biophysical setting of the study area. This permits the examination of the human-environment relationship in the context conservation scenario in Chitwan National Park, Nepal. Conservation narratives with reference to rhino population presents an evidence that human activities play a central role not only for the degradation and destruction but also for the protection of biodiversity resources through several conservation initiatives. In such conservation practice, people use their everyday experiences about surrounding landscape and perform spatial reasoning for conservation planning. This supports the concept of 'everyday experience' (Golledge, 2002) of commonsense knowledge. Human perception about wildlife movement, habitat change and reasoning about conservation planning presented in section 4.3 show that the commonsense spatial knowledge about conservation phenomena comprises several abstraction of everyday experience which is a kind of 'mental map'. Human perception about seasonal and permanent habitat change and wildlife movement pattern is related with their experiences about the reoccurrence of such events. This shows that the concept of 'Image Schemata' proposed by Jonson (1987) is also applicable for describing the way people use the imaginative patterns to understand the conservation scenario.

Conceptual representation of habitat change scenario presented in section 4.3 shows that the human understanding about the spatiotemporal change of conservation phenomena is associated with the change occurred in the surrounding landscape. Seasonal and permanent habitat change was found in terms of seasonal and yearly calendar (Figure 8). Commonsense knowledge about spatial pattern and trend of habitat change exists in mental maps as an abstraction but comprises a kind of continuous viewpoint. On the other hand, spatial representation (Figure 9) to depict the process of seasonal and permanent change only provides two snapshot view of the landscape. These results also comply with the several calls by scholars for the consideration of spatio-temporal representation and commonsense spatial reasoning in geospatial domain.

This study makes the use of commonsense knowledge gathered from the non-expert conservationists and community narratives of conservation scenario. The evaluation presentation in section 6.1 depicts that it is possible to construct geospatial ontology to describe knowledge about conservation domain and commonsense knowledge could be an alternative grounding for geospatial ontology grounding.

8.1.2 Ontology development: formal representation of commonsense knowledge

The methodology (Guidelines developed by Ordnance Survey) adopted for designing ontology in two phases (conceptual and logical ontology) lends enough space for the translation of commonsense vocabulary and multiple conceptualizations of conservation scenarios into formal ontology language. Exploration of commonsense knowledge provides varied possibility for eliciting the concepts that are essentials to characterize conservation phenomena. Furthermore, theoretical discussions regarding geographic representation (Section 2.2) and consideration of spatial and temporal entities (Section 2.3.3) provide fundamental basis to conceptualize the conservation scenario within geospatial domain.

By splitting the knowledge about conservation scenario into concept terms and relationship terms, it is possible to express the varied level of human conceptualization. Although the commonsense knowledge related to conservation phenomena exist in wide range of application domains, the possibility of describing the concept terms in logical ontology allows the exploration of the cognitive semantic view of conservation scenario. Using the description logic it is possible to conduct the formal structuring of the domain knowledge in the way that people perceive the real world and perform spatial reasoning in everyday experience. 'Protégé 4.1.beta' ontology editor provides the simplistic way for converting the conceptual ontology into logical ontology. Using the Pellet reasoner and the Description Logic query (DL query) function, it is possible to evaluate and verify the logical ontology against inconsistency and expressiveness.

8.2 Conclusion

The main goal of this study was to build geospatial domain ontology to conceptualize the human perception of conservation scenario. In this regard, the main research questions in this study were concerned with: (i) the use of ontology to conceptualize the commonsense spatial knowledge about conservation; (ii)the considerations of spatiotemporal representation in the geospatial domain to ground the dynamic conservation scenario perceived by non-expert conservationists; and (iii) competencies of ontology language for the formal representation of conservation scenario. Conclusion is provided based on the alignment of the analysis, argument with the outlined objectives and their confrontation with the research questions.

The first objective of the study is expected to deal with the first research question and analysis is provided in section 4 and 5. Results present that, with the notion of cognitive semantic, the framework of geospatial ontology is competent to ground and conceptualize the conservation narratives and everyday experience of non-expert conservationists.

The second research question is directed towards the consideration of existing spatio-temporal representation in GIS and its correspondence with the human perception of dynamic conservation phenomena. Analysis and some thought about the wildlife movement and habitat change scenarios presented in section 4.3 provides an insight to respond this questions. Results show that the conceptual representation of the human perception about habitat change scenario comprises the accumulated knowledge within the span of observation. In contrast, spatial representation of such scenarios provided in existing GIS data model such as satellite imagery only captures the snapshot view at any point within the span of observation. With the choice of top-level ontology -'DOLCE' as a foundation for domain knowledge, it is possible to establish the semantic connection between abstract human conceptualization of wildlife movement and habitat change scenario with the existing model of spatial and temporal representation in geospatial domain.

The third research question deals with the competencies of the ontology language to formalize the human perception and reasoning about conservation phenomena. Results provided in the development of conceptual and logical ontology and evaluation of the ontology presented in section 7 aims to address the third research question. Based on the description logic and reasoning functionality available in ontology editor, the ontology constructed using Protégé 4.1 is capable to infer new knowledge. Such inference knowledge also presents an agreement with the conceptualization of conservation scenario perceived by non-expert conservationist.

Although this study is designed not to employ the full flagged 'OWL Ontology' and 'Semantic Web' functionality, it provides an indication towards the call for cognitive semantic and ontology grounding to incorporate the human conceptualization of geographic space in geospatial ontology.

8.3 Future research work

The ontology designed and developed throughout this study only covers the non-expert view of conservation and ontology evaluation is carried out using intrinsic approach. Based on the ground of covered knowledge and evaluation approach, future research areas pointed out by this study are:

(i) Evaluation of the 'Conservation GIS Ontology' based on extrinsic approach

(ii) In the case of satisfactory evaluation results, further assessment with the usage scenarios such as Volunteered Geographic Information (VGI) in conservation field; and

(iii) Expansion of the ontology to integrate the expert and non-expert perspective of conservation scenario.

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APPENDICES

1. **Some photograph during the field work**

(a) Photograph during the sketch of wildlife movement

B) Community GIS training (discussion about the conservation planning and spatial reasoning)

2. Concept term description related to conservation

Concept name	Concept Description
Wildlife	Wildlife includes all undomesticated animal and lives in natural habitat
wildlife movement	Movement of wildlife from one place to other place
Daily movement	Movement of wildlife within their home range to perform daily activities
Seasonal Movement	Movements of wildlife with respect to seasonal change on habitat
Wildlife population	Total number of wildlife observed or counted within some geographic space over certain time period
Habitat	The type of environment in which wildlife normally lives or occurs
Habitat type	A classification of habitat based on the land cover/ land use characteristics
Forest area	Areas dominated by trees
Grassland	Grassland are areas where the vegetation is dominated by different species of grasses
Wetlands	Area of land covered by water permanently or seasonally
River area	Area of river channel and water course
Agricultural area	Area used for agricultural purpose
Habitat change	Change on the spatial or thematic property of habitat
Seasonal change	Change on habitat with reference to seasonal change, cyclic behavior, reoccurrence
Permanent change	Habitat change observed in long time, do not have possibility of the reoccurrence of
Human activities	All the human activities that have direct or indirect impact on wildlife, habitat, disaster phenomena and natural environment institution
Livelihood activities	Everyday activities of local community to pursue livelihood especially natural resource base livelihood activities eg. cattle grazing, firewood collection
Tourism activities	Activities provided by local community in national park and buffer zone for the tourist as part of tourisms service.
Infrastructure development	Infrastructure development in CNP and its buffer zone to support tourism activities, wildlife monitoring or habitat protection.
Conservation initiatives	Activities that are intended for the conservation and protection of wildlife and habitat
Institutions and Policy	Conservation policy implemented by various agencies to regulate the human activities in parks and its buffer zone
Conservation policy	This indicates the conservation policy formulates and implemented by agencies at local to international level
Stakeholders	Agencies involved in various conservation practice or concerns with park and surrounding landscape
Disaster phenomena	natural or man-made hazard which cause significant physical damage or destruction of habitat, loss of life, or drastic change to the natural environment
Natural phenomena	non-artificial event in the physical sense, not produced by humans, although it may affect humans
Climatic environment	Metrological phenomena eg. rainfall, temperature
Physical Environment	Landscape and their characteristic which influence the climatic environment and. All the human activity, wildlife, and habitat occurs in physical environment

3. Concept term description related to geographic representation

Term	**Synonyms/Descriptions**	**Soruce (reference)**
Geographic Feature Type	Geo Object	Fonseca, Câmara, and Monterio, 2006)
Field view	Continuous field	,,
Object view	Discrete object	,,
Human defined object	Fiat Object	,,
Natural Object	Bona Fide Object	,,
Feature Geometry	Footprint	SPRIT (Abdelmoty et al. 2005,)
Point	Centroid	,,
Line	Polyline	,,
Polygon	Area, region	,,
Geographic Location	Location description	Casati, Smith and Varzi (1998),
Relative Geographic location	Place name,	-
Absolute Geographic location	Point coordinate	-
Abstract Geographic location	description	-
Coordinate System	Spatial reference system	-

4. Concept terms description related to temporal representation

Term	Description	Source (Reference)
Abstract Temporal Representation	-	-
Temporal Unit	Time unit	W3C (http://www.w3.org/TR/owl-time/)
Duration Description	temporal sequence	,,
Temporal Entity	-	,,
Interval	things with exten	,,
Instant	an interval with zero length	,,

5. Concept terms description related to spatio-temporal particular

Term	Synonyms/Description	Source (reference)
Abstract	Entities is that do not have spatial nor temporal qualities	DOLCE Ontology (Masolo, eta al., 2002).
Endurant	Enduring entities, SNAP, instantaneous, continueants (entities that are in time)	,,
Spatial Endurant	Physical endurant	,,
Non Spatial Endurant	Non-physical endurant	,,
Perdurant	Perduring entities, occurrences, SPAN, Not- instantaneous, occurrents (entities that happen in time)	,,
Event	Sitting occurrence	,,
Process	Running occurances	,,
Quality	The basic entities we can perceive or measure (*inhere* to entities)	,,
Spatial quality	Physical qualities, directly inhere to physical endurants	,,
Temporal quality	Directly inhere to perdurants	,,
Abstract quality	Directly inhere to non-physical perdurants	,,

6. Relationship term description table

Terms	Domain	Range	Applicable Inverse	Constraints and assumption, Rule
has Effect	Human Activities, Habitat Change	Habitat Change Wildlife Movement	is effect of	some,Transitivity
has Impact	Human Activities	Disaster Phenomena	is impact of	some,Symmetric
has Influence	Habitat Change	Wildlife Movement	is influence of	some, Asymetry
hosts	Habitat	Wildlife, Human Activity, Institution Disaster phenomena	is hosted by	some,
constituent	Natural Environment	Habitat, Disaster phenomena	constituent in	some
determines	Natural Environment	Habitat, Wildlife,	determined by	some
governs	Institutional Policy	Human activity	is governed by	some
has Geographic Reference	Conservation Phenomena	Geographic Representation	is spatial reference of	some
has Feature Geometry	Conservation Phenomena	Geographic Representation	is feature geometry of	only, Functional
has Feature Type	Conservation Phenomena	Geographic Feature Type	is feature type of	some
hasGeographic Location	Conservation Phenomena	Geographic Location Description	is location description of	some
specify	Coordinate System	Feature Geometry	Is specified by	
has Temporal Reference	Conservation Phenomena	Temporal Representation	is Temporal Representation of	some, Functional
has Time	Conservation Phenomena	Temporal Entity	Is Time Of	only, Functional
has Temporal Description	Conservation Phenomena	Duration Description	is temporal description of	some
has Quality	Conservation phenomena	Quality	inherent in	only
participant	Perdurant	Endurant	participant in	some
part	Endurant, Perdurant	Endurant, Perdurant	part of	only

7. XML codes of OLW classes

7.1 Namespace

```
<Ontology xmlns="http://www.w3.org/2002/07/owl#"
     xml:base="http://www.semanticweb.org/ontologies/2011/0/5/Ontology1294186706391.owl"
     xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
     xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
     xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
     xmlns:xml="http://www.w3.org/XML/1998/namespace"
     ontologyIRI="http://www.semanticweb.org/ontologies/2011/0/5/Ontology1294186706391.owl">
    <Prefix name="xsd" IRI="http://www.w3.org/2001/XMLSchema#"/>
    <Prefix name="owl" IRI="http://www.w3.org/2002/07/owl#"/>
    <Prefix name="" IRI="http://www.w3.org/2002/07/owl#"/>
    <Prefix name="rdf" IRI="http://www.w3.org/1999/02/22-rdf-syntax-ns#"/>
    <Prefix name="rdfs" IRI="http://www.w3.org/2000/01/rdf-schema#"/>


…
```

7.2 Conservation phenomena

```
<EquivalentClasses>
        <Class IRI="#Conservation_Phenomena"/>
        <ObjectIntersectionOf>
            <Class IRI="#Conservation_Phenomena"/>
            <ObjectUnionOf>
                <Class IRI="#Disaster_Phenomena"/>
                <Class IRI="#Habitat"/>
                <Class IRI="#Human_Activities"/>
                <Class IRI="#Institutional_Policy"/>
                <Class IRI="#Natural_Environment"/>
                <Class IRI="#Wildlife"/>
            </ObjectUnionOf>
        </ObjectIntersectionOf>
    </EquivalentClasses>
…
```

7.3 Geographic representation

```
<EquivalentClasses>
        <Class IRI="#Geographic_Representation"/>
        <ObjectIntersectionOf>
            <Class IRI="#Geographic_Representation"/>
            <ObjectUnionOf>
                <Class IRI="#Abstract_Geographic_Representation"/>
                <Class IRI="#Feature_Geometry"/>
                <Class IRI="#Feature_type"/>
                <Class IRI="#Geogaphic_Location"/>
            </ObjectUnionOf>
        </ObjectIntersectionOf>
    </EquivalentClasses>
…
```

7.4 Temporal representation

```
<EquivalentClasses>
        <Class IRI="#Temporal_Representation"/>
        <ObjectIntersectionOf>
            <Class IRI="#Temporal_Representation"/>
            <ObjectUnionOf>
                <Class IRI="#Abstracct_Temporal_Representation"/>
                <Class IRI="#Temporal_Entity"/>
                <Class IRI="#Temporal_Unit"/>
            </ObjectUnionOf>
        </ObjectIntersectionOf>
    </EquivalentClasses>
…
```

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