METHODOLOGY FOR INTEGRATION OF FISHERS' ECOLOGICAL KNOWLEDGE IN FISHERIES BIOLOGY AND MANAGEMENT USING KNOWLEDGE REPRESENTATION [ARTIFICIAL INTELLIGENCE]

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ABSTRACT

The fisheries crisis of the last decades and the overexploitation of a great number of stocks (FAO 1995) have been due mainly to the inadequacy of scientific knowledge, uncertainties in assessments and/or failures of the management systems. These problems are critical when the management of coastal ecosystems and artisanal fisheries is involved. These systems possess great complexity due to the high number of human factors that influence their functioning and the fishing activity. Small-scale coastal fisheries have a much greater social significance than offshore industrial fisheries, despite the larger economical importance of the latter (only in macro-economic terms).

The artisanal coastal fisheries in Galicia (NW Spain) are in a general state of overexploitation derived from the mismatch between management (derived implicitly from models designed for industrial finfisheries) and the biological and socioeconomic context. Freire & García-Allut (2000) proposed a new management policy (based on the establishment of territorial users' rights, the involvement of fishers in the assessment and management process in collaboration with the government agencies, and the use of protected areas and minimum landing sizes as key regulations) to solve the above problems. As well as a new management system, research should pay special attention to the design and use of inexpensive and rapid methodologies to get relevant scientific data, and introduce local or traditional ecological knowledge of the fishers to the assessment and management process.

In this paper, we analyze the values and characteristics of fishers' ecological knowledge (FEK). Using the artisanal coastal fisheries of Galicia as a case study, we present the objectives of the integration of FEK in fisheries biology and management and propose a methodology for that goal. The use of Artificial Intelligence (AI) as a tool for the analysis and integration of FEK is discussed, and the role of *Knowledge Representation,* a branch of AI, is described to show the epistemological and technological adequacy of the chosen languages and tools in a non-computer science forum.

INTRODUCTION

World fisheries are in crisis. According to the FAO (1995), 69% of the world's marine stocks are either fully to heavily exploited, overexploited or depleted, and are therefore in need of urgent conservation and management measures. The causes of the collapse of exploited marine populations have been the subject of wide debate, pitting those who believe that excessive fishing effort leads to over-exploitation, against those arguing that fluctuations in population dynamics are attributable to natural environmental changes. Myers and other researchers in (1996 and 1997) studied the collapse of the cod fishery in Newfoundland and concluded that the overexploitation hypothesis is backed by scientific evidence which is much stronger than other related to environmental changes. The collapse of stocks constitutes the final stage of overexploitation generated by an excessive fishing effort. This process may be attributed either to a lack of appropriate scientific information or, on occasion, where there *was* suitable assessment, to faulty management systems or failure to enforce the compliance of several fisheries.

In the case of artisanal fisheries in Galicia (NW Spain) there are also a number of indicators that reveal overfishing (Freire 1999; Freire 1000a): 1) the virtual depletion and collapse of several stocks (for example lobster, spiny lobster, sea bream) whose catches are irrelevant today but were important historically in the area, 2) the time series of catches that, despite problematic interpretation, show that there has been a decline in many cases from the 1940s-60s to the present time, e.g. crustaceans, and 3) specific assessments, such as on the spider crab in the Ría de Arousa (Freire 1000b) reveal exploitation rates greater than 90% per fishing session. As well as showing indicators of overfishing, the following differential characteristics of the artisanal sector complicate the design of successful management systems:

1. From a biological standpoint, the species harvested by the artisanal coastal fleet of Galicia, and particularly the great majority of invertebrate species, present a number of characteristics which render useless the classical analytical models of finfish population dynamics used in the management of industrial fisheries. These species, sedentary benthic or mobile benthic/ demersal, have a strong and persistent spatial structure and are characterized by the following: 1) complex life cycles (planktonic dispersing larval stages and sedentary or low mobile benthic or demersal postlarval stages), 2) a spatial distribution characterized by the existence of aggregations which are evident on different scales, 3) a population structure that could be defined as meroplanktonic meta-populations in which the postlarval stages make up a chain of local populations along the coast with low migration and dispersal levels, interconnected by a planktonic larval stage, and 4) the aggregated stock-recruitment relationship is not applicable to a segment of a metapopulation.
2. In an industrial fishery, the relationships between the economic benefits obtained by the fishery and its biological and social complexity is high, which would make it possible to fund and develop intensive lines of research. In terms of the artisanal coastal fisheries of Galicia, the economic yield of each of the species harvested does not appear to be able to support specific lines of research which could complete our incomplete scientific knowledge.

Faced with these scenarios, some argue that finding ways to incorporate fishers' participation would improve our capacity to manage fisheries sustainable. Neis (1999) presents a methodology for collecting and integrating fishers' ecological knowledge into resource management, but the formal representation of this knowledge is not addressed. We believe that formal representation using AI (specifically *Knowledge Representation*) techniques could not only assist in the acquisition and refinement of this knowledge, but could also facilitate comparison with other knowledge systems (scientific knowledge), the observation of possible changes in these over time, and the impact of both knowledge systems on management initiatives. The aim of this paper is to a) show that *Description Logics* and *Terminological Systems* are good candidates for this task, b) describe the methodology designed to carry out this task, c) develop a case study implementing this and d) document the evaluation by biologists.

Also, following this line of work, it is worth mentioning a *fuzzy logic* expert system whose knowledge base incorporates fishers' knowledge in the form of heuristic rules (Mackinson and Nottestad 1998). Consequently our approach complements the work in (Neis 1999) and (Mackinson 1998) both in content and methodological aspects.

The remainder of the paper is organized as follows. The next section defines the concept of Fishers' Ecological Knowledge (FEK) which is rooted in ethnoscience and cultural ecology traditions. Section 3 argues that given the characteristics of FEK and what we want to do with it, *Description Logics* (DLs) are a good choice to represent FEK. In section 4 we describe our methodology. A visual terminological language which has been designed to facilitate knowledge input is described in section 5. The paper ends with some conclusions.

Fishers' Ecological Knowledge

FEK is a specialized branch of TEK (Traditional Ecological Knowledge). The concept of TEK appeared in the mid-1980s, and social scientists have argued that it represents at least a critical supplement to scientific understanding. Mailhot (1993) gave an explanatory definition of TEK:

> *"the sum of the data and ideas acquired by a human group on its environment as a result of the group's use and occupation of a region over many generations"*.

FEK (Neis 1999) typically includes not only categories of fishes, but also information on behavior, ecology, meteorology and oceanography, and references to time and space that can complement scientific knowledge. Moreover, FEK is an updated understanding that includes the latest changes occurring in the local marine environment. However, those who plan management policies are usually politicians who work unilaterally in collaboration with technicians from the administrations, and disregard entirely the knowledge of the fishers within their field of experience. Some examples that occurred in Galicia in recent years may serve as an illustration. Artisanal fishers used the traditional fish trap (cylindrical and closed) to fish velvet swimming crab and octopus. In order to regulate these resources, the administration required fishers to employ a more selective type of trap (square and open) designed by its technicians to fish exclusively octopus. The fishers bought these new traps and soon discovered that they were inefficient. They required more work and produced less. The response of fishers was to replace the new traps with the traditional ones behind the back of the administration. This process went on for several years before the administration recognized its error which had resulted in an economical setback for the artisanal fisheries. The government, in opposition to an important sector of fishers, also opened the fishing season for velvet swimming crab at a critical time of its reproduction, thus putting the stock in danger. This latter situation example continued for several years.

Therefore, our main objective is to acquire new knowledge that can be applied to the sciences involved in designing management models for artisanal fisheries in Galicia. The generic scope of knowledge that we will need to achieve the above goals will be centred, in turn, on acquiring knowledge and information on coastal ecosystems, population dynamics, descriptions of habitats and bottom types, interactions and relationships between species, behavior and feeding habits, reproductive zones and seasons, climate (atmospheric and oceanic) influences on the species, stock assessment of fishes, crustaceans and molluscs, reconstruction of the history of marine ecosystems in relatively short periods, etc. After filtering, systemizing and formalizing fishers' ecological knowledge, it can contribute to broaden our understanding of many of these topics.

METHODOLOGICAL CHOICE: DESCRIPTION LOGICS

It has been recognized by Neis (1999) that the main hurdle associated with combining science and FEK is methodological: finding ways to combine these two knowledge systems. In (Neis 1999) and other works, methodologies and research techniques to acquire traditional knowledge are described. These include: analysis of discourse, selection of information, semi-guided open interviews, surveys on specific points of knowledge, analysis of the distribution maps of the resources and habitats drawn up by the fishers (Ames, this volume), and other documents of a functional nature that they may have, such as notebooks and graph interpretations (depth sounder, radar), etc. This work is being done almost exclusively by anthropologists and this knowledge circulates mostly through channels of dissemination of maritime anthropology. If this knowledge could be represented in a formal manner, it could be refined, reused, shared with others or integrated with biological knowledge in a principled way. Therefore *Knowledge Representation* (KR) plays an important role in improving the knowledge of biologists, technicians, anthropologists and fishers, with the ultimate goal of designing better fisheries policies.

Two main properties of FEK are that it is a very large body of knowledge and it is subject to continuous changes. Up to now, anthropologists have seen the work of formalizing FEK as part of their research area. This situation motivated us to seek a methodology where the anthropologist is not only an end-user of the resulting knowledge-based system, but he/she is involved in the knowledge engineering process from the beginning. Anthropologists can certainly break down the domain into its characteristic elements, even possibly express them in a computer language. However these tasks must be accomplished in the framework of a formal model, since the lack of a formal semantic foundation could lead to several problems such as inconsistencies or circular definitions. Therefore, to be successful the *Knowledge Representation Language* (KRL) must be carefully selected. Epistemological adequacy must derive from the nature of FEK. Note that one of the major components of FEK is the categorization used by fishers to classify components of the environment and the organization of these categories into a system of representation. From a technological perspective we need a language that is both expressive and easy to learn. Implementations of DLs seem to be the right choice.

From a logical and formal view, DLs integrate research done in semantic networks, frame systems and other object-oriented representations, and constitute the formal successor of the family of KL-ONE languages (Brachman 1985). During the last fifteen years the main issue of research in Description Logics has been the identification of the sources of intractability. The results of this research allow us to depart from a very basic language and to increase expressiveness while ensuring computational tractability.

The primary aim of DLs is to express knowledge about *concepts* and *hierarchies of concepts*. DLs have declarative tarskian semantics and can be identified as sublanguages of *First Order Logic* (FOL). A *concept expression* is a general description of a class of objects in the target domain. Concept expressions are formed using various *constructors*, some of them expressing relations with other concepts (roles). Relations expressed by means of roles, can be qualified in several ways (type restrictions, value restrictions, number restrictions, etc.). Just by analyzing concept expressions, a taxonomy of concepts following generality-specificity criteria can be built. The efficient implementation of reasoning services is based on this hierarchical structure.

The basic blocks of the descriptive languages are atomic concepts and roles. Atomic concepts can be considered as unary predicates, and atomic roles can be considered as binary predicates. Atomic concepts and roles are combined to build complex concepts and roles. Semantics allows the interpretation of concepts as subsets of objects (here called individuals) of the domain and the interpretation of roles as binary relations between objects of the domain. Therefore the extension of a concept is a set of individuals, and the extension of a role is a binary relation between individuals. Also following the semantics of language constructors, the equivalent in FOL of any concept or role expression can be obtained.

Satisfiability and subsumption are the basic inferences in DLs. A concept is satisfiable if it can have a on-empty extension. A concept C is subsumed by a concept D if the extension of C is always a subset of the extension of D. Other inference tasks of great utility such as equivalence or classification can be reduced to satisfiability and subsumption. Reasoning about individuals is also provided with these logics. Since the seminal works in the field (Levesque 19 and 1987), reasoning in DLs and the tradeoff between expressiveness and tractability have been deeply studied, leading to important results - see Donini (1997) for a survey.

Terminological languages (also called concept languages) are implementations of DLs. *Classic* (Patel-Schneider 1991) and *Fact* (Horrocks 1998) are examples of well-known terminological languages. These languages allow us to define concepts and roles, to organize them by means of taxonomies, to define individuals and to make inferences on these elements and structures. Practical applications of description logics (terminological systems) using these and other terminological languages exist in a wide variety of domains: data and knowledge management systems (Borgida 1993 and 1995), global information systems (Levy 1995), clinical information systems (Rector 1997), software engineering (Devanbu 1991), etc.

In our project, we have chosen to use *Classic* for several reasons. The language is expressive enough to be useful and limited enough to assure tractable reasoning. The language is simple and small enough to be really usable because it can be learned by non-experts in computer science. Even a methodology for using *Classic* has been published (Brachman 1991). This knowledge engineering methodology has been elaborated, emphasizing the modeling choices that arise in the process of describing a domain and the key difficulties encountered by new users. The language has additional features that increase usability such as a limited forward-chaining rule system and the possibility of concept definitions written as test functions in a procedural programming language. However, these additional features are designed following the principle that user code cannot subvert the knowledge representation system, that is, these additional features have to be kept opaque and should not destroy the correspondence between the reasoning subsystem and the formal semantics - Lisp, C and C++ implementations of *Classic* exist, and an API (Application Programmer's Interface) is available. The distribution is now being handled by Bell Labs and licenses for research and commercial use can be obtained (ATT 1999).

Putting it into practice

This section shows our methodology from the following points of view: 1) interdisciplinarity, 2) description of the case study, 3) formulation of the case study and 4) evaluation of the results by a biologist.

Interdisciplinarity

The framework in which this research has been carried out is characterized by the convergence of anthropological and marine biological objectives for obtaining new knowledge about Galician coastal ecosystems. The final objective is to improve and increase biological knowledge of the coastal ecosystems and to apply it in the management of Galician artisanal fisheries. In summary, this process has been carried out in the following way:

- The original question (posed by the biologist) is related to the search for information (data) and knowledge about species of fishery interest;
- In the population-dynamics framework, a catalogue of themes to elicit is established in the fishers' communities under study;
- Using social science methodologies, a large corpus of knowledge relating to this field is obtained;
- The knowledge is systematized and methodologies of closed interviews, discussion groups, etc., are applied;

- Since the knowledge obtained from fishers is much extended, one specific topic, the microhabitats, was selected to be formalized.

Description of the case study.
When speaking about coastal ecosystems, fishers frequently mention elements and descriptive characteristics of the marine benthic habitats associated with the presence of different species. Also, in their descriptions, fishers include variables such as depth, tides, time, season, climatology, etc. This knowledge, once it has been systematized, allows the construction of a typology of bottom classes and their relationships with the species. Since both the knowledge and the information about this topic is extensive, we selected it as the topic of study.

Specifically, the relationship among different types of rocky bottoms (microhabitats) and a selection of species (involving crustaceans, molluscs and fishes) is described. Other species, such as seaweeds or echinoderms, were excluded to make the results easier to understand.

For rocky bottoms, fishers differentiate spatial and morphological categories according to the types of rocks and the species using the different microhabitats. The rocks are characterized using morphological factors such as form, size, rugosity, height, etc (BOLO, LAXA, PETON, PEDRA BRAVA, CHAN, LAXA, CABEZO, etc.). These categories are related to their location and extension over the bottom, constituting characteristic microhabitats: VEIRADAS, BOLEIRAS, OIADOS, RODAS, etc. Fishers use these microhabitats as the conceptual background to their daily fishing operations decision-making.

Definition of some of the concepts used by fishers:
"Bolos": smooth and round rocks.
"Boleiras": a zone of boulders of variable size extended randomly over a smooth rocky substrate.
“Laxa”: flat rock .
"Laxeado": area of flat rocks covering surfaces of up to 6000 m^2.
"Pedra brava": rock with strong rugosities.
"Chans": rocky bottoms without relief.
"Cabezo": a rock with a high relief but always underwater.
"Veiradas": transition between sandy and rocky bottoms.
"Oidados": areas with mixed rocky and sandy bottoms. Usually small areas, between 50 and 100s of m^2.
"Roda": small area of rocks inside a large sandy bottom.

Formalization of the case study
We must recall that our goal is not only to represent FEK; but also that the anthropologist become involved in this task. We distinguish three phases.

1. The anthropologist is trained in the basic concepts of terminological languages.
2. The domain must be broken down into its elements in accordance with the representation basics.
3. The result of the second phase must be transformed in *Classic* expressions.

Firstly, the anthropologist must acquire the basic concepts of descriptive languages: individuals, concepts, roles and taxonomies. This can be done in an informal but fair way without resorting to formal model-theoretic notions. DLs are particularly well suited to this process because their basic elements can be explained just using elementary set-theoretic and algebra concepts.

When developing a Knowledge Base (KB) in a terminological language, the second phase is a knowledge engineering process where the key is finding the way to break the domain into individuals, concepts and roles. In the case of *Classic* a methodology especially devised for beginners is available (Brachman 1991). Though this method may oversimplify some aspects of the knowledge representation process, it is ideal for our purpose of introducing the anthropologist to using Classic. The method consists of twelve basic steps exemplified with the *wine and meal* example: 1) enumerate object types, 2) distinguish concepts from roles, 3) develop concept taxonomy, 4) isolate individuals and for each individual try to determine all of the concepts that describe it, 5) determine properties and parts, 6) determine number restrictions, 7) determine value restrictions, 8) detail unrepresented value restrictions, 9) determine inter-role relationships, 10) distinguish essential and incidental properties, 11) distinguish primitive and defined concepts, 12) determine disjoint primitive concepts.

Background:

- The example analyzed here has not been the subject of specific scientific studies, at least in our area.
- There is a previous general knowledge of the habitat use of the species, basically using wide habitat categories defined by the type of substrate (sand / rock), which is not useful for management objectives.

```
(createRole shape true)
(createRole rugosity true)
(createRole fastening true)
(createTole size true)
(createrole surface-closeness true)
(createRole height true)
(createRole fishes)
(createRole bordering true)
 (createRole rocktype)
(createRole sand true)

(createConcept ROCK (and  (all rugosity (oneOf Smooth Rough))
                          (all shape (oneOf Rounded Flat))
                          (all fastening (oneOf Fastened Loose))
                          (all size (oneOf Small Medium Big))
                          (all surface-closeness (oneOf Near Far))
                          (all height (oneOf High Low))))

 (createIndividual Bolo (and ROCK (fills rugosity Smooth)
                          (fills shape Rounded)
                          (fills fastening Loose)
                          (fills size Small)))

(createIndividual Laxa (and ROCK (fills rugosity Smooth)
                          (fills shape Flat)))

 (createIndividual Peton (and ROCK (fills fastening Fastened)
                          (fills height High)))

 (createConcept FISH (oneOf Wrasse-female Wrasse-male Turbot
                          (Sea-bream Velvet-swimming-crab Octopus Conger-eel Bib))

(createConcept ENVIRONMENT (and (all bordering (oneOf Yes No))
                          (all rocktype ROCK)
                          (all sand (oneOf Yes No))
                          (all fishes FISH)))

 (createConcept OIADOS (and ENVIRONMENT (fills bordering No)
                          (fills rocktype Bolo)
                          (fills sand Yes)))

 (createConcept VEIRADAS (and ENVIRONMENT (fills bordering Yes)
                          (fills sand Yes)))

(createConcept RODAS (and ENVIRONMENT (fills bordering No)
                           (fills rocktype Peton)
                          (fills sand Yes)))

(createConcept BOLEIRAS (and ENVIRONMENT (fills bordering No)
                          (fills rocktype Bolo)
                          (fills sand No)))

(createRule one VEIRADAS (and   (fills fishes Wrasse-female)
                          (fills fishes Wrasse-male)
                          (fills fishes Turbot)
                          (fills fishes Sea-bream)
                          (fills fishes Velvet-swimming-crab)
                          (fills fishes Octopus)))

(createRule two OIADOS (and (fills fishes Conger-eel)
                          (fills fishes Wrasse-male)
                          (fills fishes Turbot)
                          (fills fishes Sea-bream)
                          (fills fishes Velvet-swimming-crab)
                          (fills fishes Wrasse-female)))

(createRule three RODAS (and   (fills fishes Bib) ))
             (createRule four BOLEIRAS (and  (fills fishes Conger-eel)
                          (fills fishes Octopus)
```

Figure 1. Terminological Knowledge Base written in Classic

Practice with this method is done through the use of real examples extracted from FEK. For instance, the anthropologist has useful knowledge about rocks (*laxa, bolo, petón*), clusters of rocks (*veiradas, oiados, boleiras, rodas*) and species associated with these *environments* or microhabitats. Following the method, this domain is decomposed into elements of the terminological language. The result of the second phase is an informal representation that in the third phase must be transformed into a *Classic* KB. To serve as an example, Fig. 1 shows the *Classic* KB with fishers' knowledge about microhabitats of some species of interest.

The following lines explain the meaning of the KB. The first ten terminological axioms define the set of roles of the KB using the function *createRole*. *Roles* are the entities that represent the properties of individuals. They map individuals to other individuals. The roles of an individual can be filled by individuals (the role fillers) or have their potential fillers restricted by concepts, or both. Each role definition includes the name of the new role and the boolean specifies whether the role is an attribute. An attribute is a role that has at most one filler. For instance, size is an *attribute* because we use this role to model a property for rocks and a rock is supposed to have a specific size. On the contrary, 'fishes' is not an attribute because this role models the relationship between an environment and the fishes within it. Clearly, within an environment different species can occur. The first six role axioms correspond to properties for rocks and the last four role axioms define environmental features. After creating the roles, we define the concept ROCK by means of the function *createConcept*. In this terminological axiom the symbol ROCK is the name of the concept being defined and the description is the concept definition. The 'and' concept constructor creates the conjunction of a number of descriptions. The 'all' restriction specifies that all the fillers of a particular role must be individuals described by a particular description, and 'one-Of' is a concept constructor which forms a concept enumerating its individuals. Therefore, the axiom defining ROCK includes a domain constraint for each one of the properties of a rock. In this case, the domain is constrained by specifying the set of individuals that can be fillers for each role. For instance, the 'rugosity' of a rock has to be either smooth or rough or the shape has to be either rounded or flat. Individuals are specific instances of concepts that are used to represent the real-world objects of the domain. Individuals are created by means of the function 'createIndividual'. In the function call, the first symbol is the name of the individual being created, and the description is the definition of the individual. The 'fills' concept constructor specifies that a particular role is filled by the individuals specified. Once a rock is defined, the individuals Bolo, Laxa and Peton are created. As an example, Laxa is an individual belonging to the concept ROCK whose rugosity is smooth and whose shape is flat. The definition of the concept FISH simply specifies the set of its individuals. The concept ENVIRONMENT models *environments* as sets of individuals whose rocktype property is constrained to be a ROCK (all rocktype ROCK) and where several types of fishes can occur (all fishes FISH).
Environments can have sand [all sand (oneOf Yes No)] and can border other elements [(all bordering (oneOf Yes No)]. The concepts VEIRADAS, OIADOS, RODAS and BOLEIRAS are subconcepts of ENVIRONMENT with specific fillers for the involved roles. Specific instances (individuals) of these concepts representing specific locations of these environments could be added to this knowledge base. The final lines of the KB define several *rules* via the function 'createRule'. A *rule* consists of an *antecedent*, which must be a *concept*, and a *consequent*, which is a *concept description*. As soon as an individual is known to belong to the antecedent concept, the rule is fired, and the individual is deduced to belong to the consequent description. The individual does not need to be described by the consequent in order to be classified under the antecedent. Once the rule is fired, the individual is further classified based on the new information provided by the rule. These rules allow us to infer automatically the set of species occurring in a given environment. For instance, from the third rule, each individual belonging to the concept RODAS has the species Bib (*Trysopterus luscus)* as one of its fillers for the role fishes. This way, when defining an environment we do not have to specify the set of fishes that occur, but the system infers them automatically. The use of rules permits to distinguish between definitional and incidental properties. The set of fishes living in a given environment is not a definitional aspect for the environment but the definitional aspects of an environment, i.e. shape, rocks, etc., are the elements that really determine the set of fishes which can live within those conditions.

Since we have to provide the biologist with the results obtained in an understandable and efficient format, we have drawn graphical representations e.g. Fig. 2. In these graphical representations we use the notation of Gaines (1991). It is important to point out that, for the sake of clarity, we allow duplication of graphical nodes that are associated with a single knowledge representation element. Note also that the graphical syntax of Gaines (1991) allows only defined concepts as consequents in rules, but *Classic* allows any concept description in the consequent part of a rule and not just a defined concept. These unnamed concepts are simply represented in Fig. 2 as ovals without labels. We have recognized a multiple purpose of this graphical representation: 1) it reinforces the knowledge engineering methodology, 2) it has been used to explain FEK to biologists and technicians and 3) it has motivated us to implement a visual terminological language which facilitates the task of writing *Classic* KBs thus giving more weight to the role of the anthropologist in the knowledge engineering process and providing a tool to overcome the difficulties presented in the third phase.

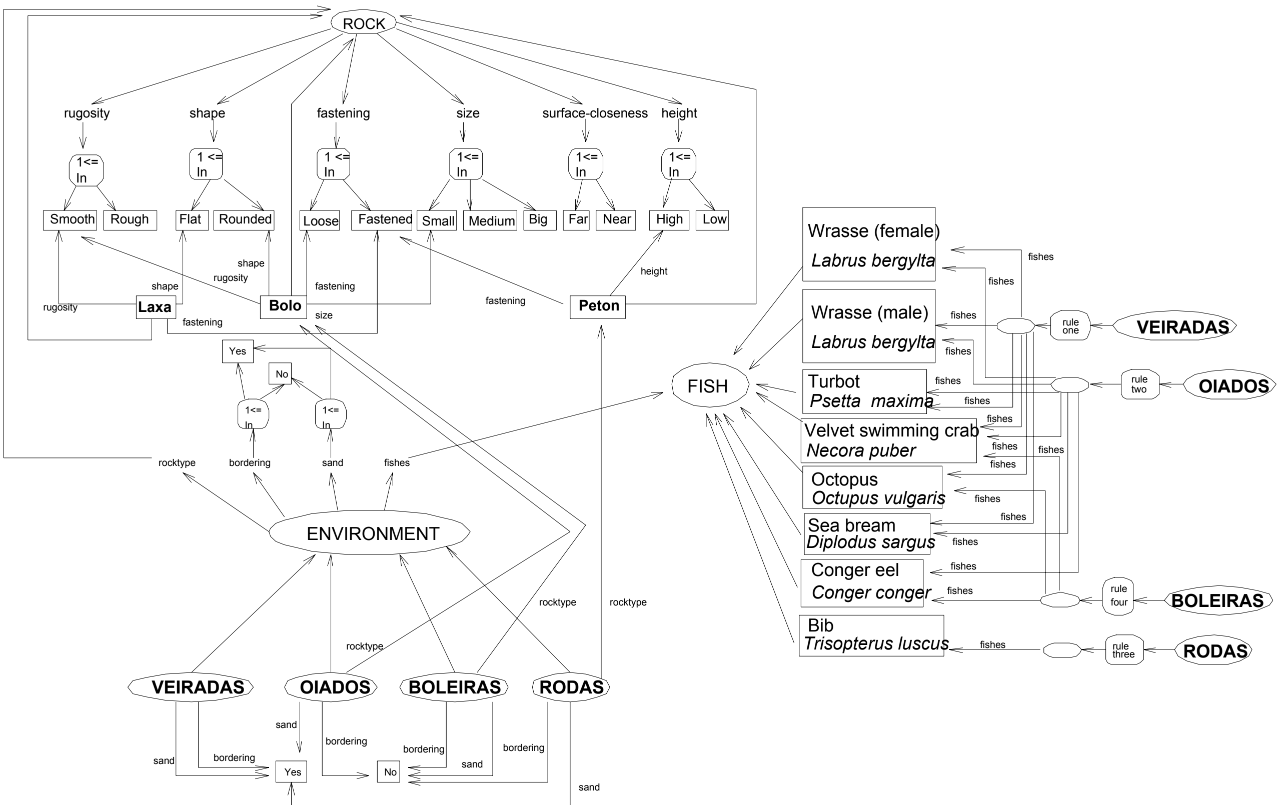

Figure 2. Graphical representation of the terminological knowledge base

EVALUATION OF THE RESULTS OBTAINED OF THE ANALYSIS OF THE FEK

Representation of the knowledge

Biologists are used to working with information in a tabular format where all variables of interest are explicit; this fact limits the usefulness of the raw verbal FEK. The representation of the knowledge base obtained *translates* the original FEK to a format operative for biological analysis. The diagram obtained clearly reflects these components and relationships and allows the biologists to use this semi-quantitative information in their hypotheses and models.

Biological knowledge obtained

The results obtained constitute new information about the problem analyzed. In brief:

- the basic components of the habitat (different kinds of rocks, defined by their morphology and size) are identified,
- the microhabitats are the result of the spatial configuration in the small-scale of these components,
- each species shows a different pattern of use of the microhabitats here identified.

The level of detail attained is very high in comparison with typical biological sampling or experimental studies, indicating the importance of some habitat features usually overlooked in scientific studies.

Potential uses of the results obtained

Two basic applications are identified in the biological and fisheries management contexts:

- *Generation of hypotheses to be tested using scientific methodology*. The results of the FEK offer new ideas to understand the patterns of habitat use and should be the basis to design new studies that could test these ideas.
- *Fisheries management*. In coastal ecosystems exploited by artisanal fleets, management models are changing from direct effort regulations to systems based on regulation of the use of space. In this context, knowledge of the species-habitat relationships is fundamental to assess the value of different areas and to optimize their human uses. The results of the FEK analyses combined with maps of the distribution of the habitat components would allow rapid assessment of the value of different areas and the proposal of management strategies based in different uses of areas.

Visual terminological language

To facilitate the use and understanding of these methodologies to other potential users (fishery technicians, biologists, fishers, etc) we decided to use help tools for this task. For this reason we transformed these languages into visual languages to improve the usability. In this section we describe a visual terminological language for *Classic* and give a sketch of the implementation.

The visual language

For the sake of being concise, the visual syntax is illustrated with figures 3, 4 and 5.

Visual descriptions.

Fig. 3 shows the visual descriptions that can be built with concept constructors, and the corresponding *Classic* expressions. *Classic* has no role constructors, therefore the only role expressions are formed with atomic roles. For this reason there are no additional visual role descriptions.

Visual axioms and rules.

Concept descriptions and atomic roles and attributes are used in the axioms that define concepts, individuals and roles, and in the rules definition. The visual axioms and rules, and the corresponding Classic expressions are shown in Fig. 4.

Temporal definitions.

The visual language provides temporal definitions for concepts, individuals and rules. These elements allow us to differentiate between what is being defined (temporal axioms and rules) and what is actually defined (real axioms and rules). Fig. 5 shows a temporal definition for the case of a defined concept.

Implementation

Visual descriptions, axioms, rules and temporal definitions are represented as Directed Acyclic Graphs (DAGs). Operations over these visual elements are implemented as operations over graphs. Fig. 6 shows the main window of the interface for this visual language. In the normal operation and using the buttons on the left, the user can define roles and attributes, build visual descriptions, attach them to concepts and individuals to create temporal definitions and eventually transform these temporal definitions into axioms and rules. The result is a visual knowledge base, i.e. a collection of visual axioms and rules subject to certain rules that facilitate the visual representation. For instance, note how in Fig. 6 the representation of the visual axioms for the definition of Bolo and ROCK avoid the duplication of the ROCK node, but for reasons of clarity in the visual representations, duplication of nodes corresponding to the same role rugosity is allowed. Also note that roles do not carry descriptions with them due to the absence of role constructors, this facilitates the graphical duplication of role nodes.

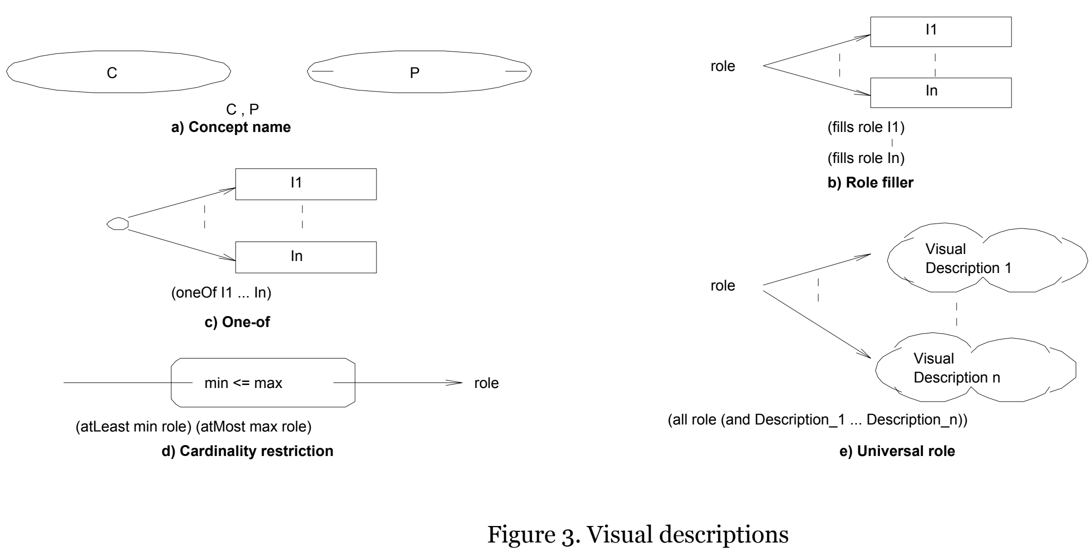

Figure 3. Visual descriptions

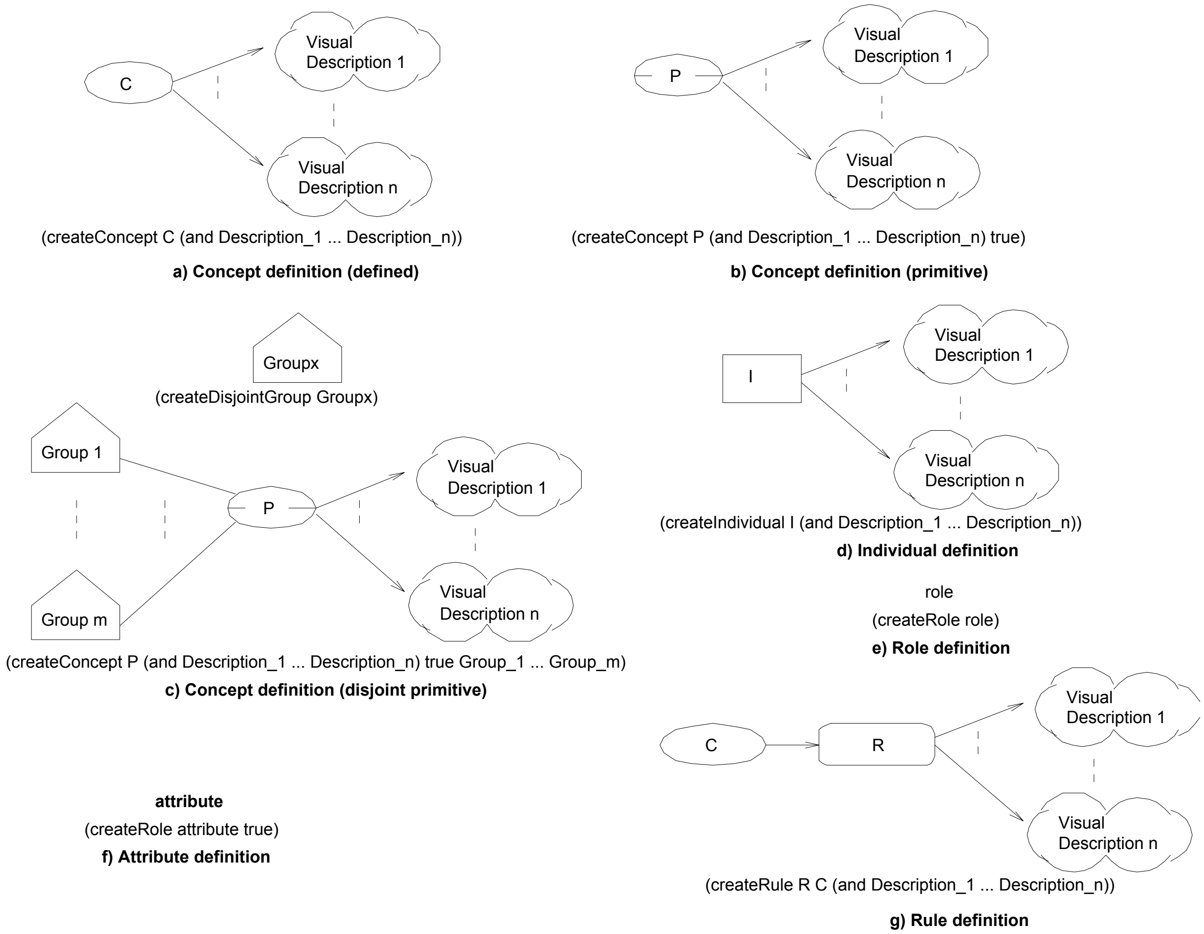

Figure 4. Visual axioms and rules

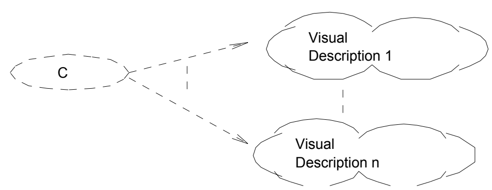

Figure 5. Temporal definition of a defined concept

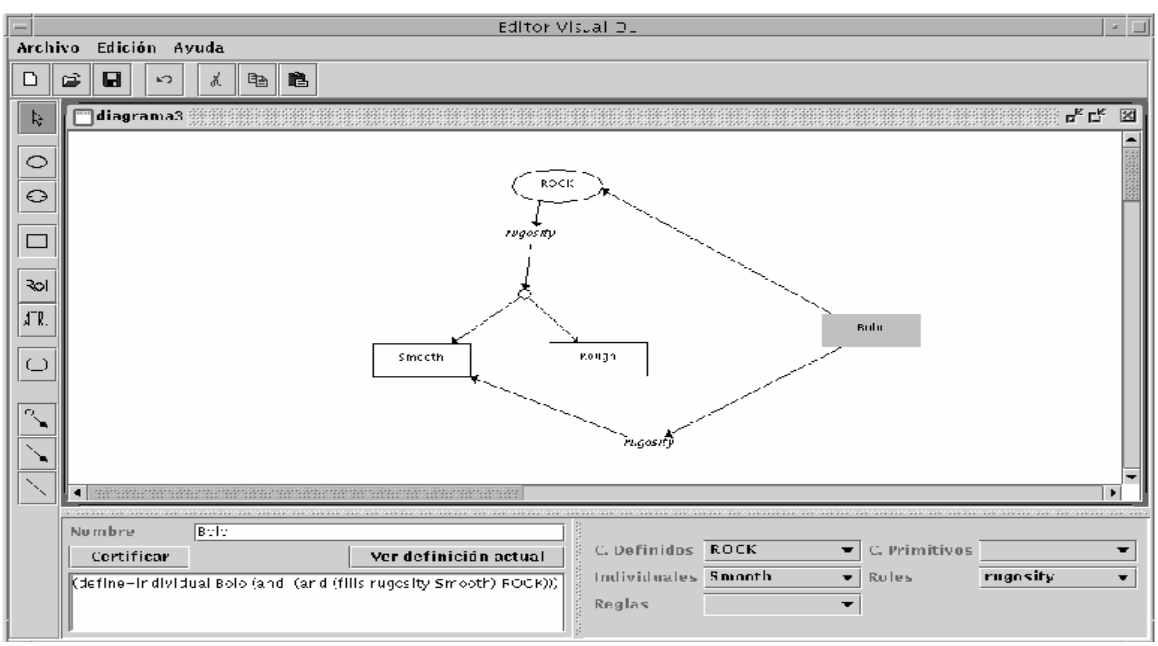

Figure 6. Interface for the visual language

Conclusions

We have presented a methodology to incorporate Fishers' Ecological Knowledge in the research of artisanal fisheries based on a knowledge representation formalisation and a knowledge engineering technique reinforced with the appropriate tools. An evaluation of this work in terms of usability, productivity and knowledge content is still to be done and in this task anthropologists, biologists and fishers themselves must be involved. But preliminary results are encouraged and we think that this approach can be considered in other domains where Traditional Ecological Knowledge can be incorporated into the management of natural resources.

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