An Interdisciplinary Insight into the Human Dimension in Fisheries Models. A Systematic Literature Review in a European Union Context.

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Abstract

Fisheries are complex adaptive social-ecological systems (SES) that consist of interlinked human and ecosystems. Thus far, they have mainly been studied by the natural sciences. However, the understanding and sustainable management of fisheries will require an expansion of the study of the human element in order to reflect the SES perspective. Models are currently the most common method used to provide management advice in fisheries science, and these, in particular, will have to expand to include the human dimension in their assessment of fisheries. The human dimension is an umbrella term for the complex web of human processes within a social-ecological system and as such it is captured by disciplines from the social sciences and the humanities. Consequently, capturing and synthesizing the variety of disciplines involved in the human dimension, and integrating them into fisheries models, will require an interdisciplinary approach. This study therefore attempts to address the current shortcomings associated with the modelling of fisheries in the European Union and advise on how to include the human dimension and increase the interdisciplinarity of these models. We conclude that there is potential for the expansion of the human dimension in fisheries models. To reach this potential, consideration should be given to e.g. early involvement in model development of all relevant disciplines, and the formulation of operationalisable theories and data from the human dimension. We provide recommendations for interdisciplinary model development, communication, and documentation in support of sustainable fisheries management.

1 Introduction

Fisheries have been recognised as a social-ecological system (SES). As such, they consist of a coupling of a human system with a natural one (Ostrom, 2009). These two subsystems are connected and intertwined, and have a two-way feedback relationship, where a change in one of the subsystems can impact the other, and vice-versa (Berkes, 2011). Fisheries also have the characteristics of complex adaptive systems, such as non-linearity, uncertainty, and self-organisation (Leenhardt et al., 2015; Levin et al., 2012). Thus, fisheries can be understood as social-ecological complex adaptive systems (SECAS). Today, the SECAS perspective on fisheries has been acknowledged, yet fisheries are not always addressed as such (Syed, Borit, & Spruit, 2018).

The field of fisheries science has been traditionally dominated by natural scientists (Link, 2010). Their research efforts have focused mainly on topics relating to the natural subsystem (Syed et al., 2018). However, these efforts need to expand to include the human subsystem in order to ensure that fisheries science is addressing both elements of the social-ecological system, especially as a lack of consideration of the SES perspective in general, and the human subsystem in particular, has led, in some cases, to management and policy failures in the past (Freire & Garcia-Allut, 2000; Österblom et al., 2011). Thus, it is only through equal consideration of both subsystems that fisheries science can provide a SECAS perspective. In return, it is only through a SECAS perspective that the field can capture the complexity of fisheries appropriately, and contribute to effective sustainability, conservation, and management initiatives (Marshall et al., 2018; Rissman & Gillon, 2017; Starfield & Jarre, 2011).

Fisheries science uses modelling approaches to assess fisheries systems and to provide management advice. As such, models are the most commonly used method in this field (Jarić, Cvijanović, Knežević-Jarić, & Lenhardt, 2012). A common way to integrate various data and additional considerations on, for example, theory or indicators (Link, 2010, p. 89), models can provide an inspiring point of departure and a guiding principle for interdisciplinary (e.g. (Heemskerk, Wilson, & Pavao-Zuckerman, 2003)), and as such models have a high potntial to be used as an integrative research method in itself. Consequently, including considerations of the human subsystem into these models will provide a better assessment of fisheries as SECAS, while supporting their sustainable management. However, the human subsystem is not easily captured, as it is a broad and diverse field of study.

The umbrella term 'human dimension' in relation to fisheries has been used in order to refer to the diversity within the human subsystem and to highlight its importance (Charnley et al., 2017; OECD, 2007). The human dimension (HD) can be understood as a complex web of human processes that relate to natural resources (Spalding, Biedenweg, Hettinger, & Nelson, 2017) . It can be categorised into social phenomena, social processes, and individual attributes (Bennett et al., 2017). To study the HD, human dimension aspects (HDA) (i.e. smaller components within an HD category) are often analysed, such as compliance or trust. Due to the diversity of the human subsystem, the HD and its HDAs are addressed by many different disciplines, ranging across the social sciences and the humanities. This makes the HD a ***broad multi- and interdisciplinary concept*** that can be studied from various angles and at different scales, from global to local (Bennett et al., 2017; Spalding et al., 2017). Thus, interdisciplinary approaches are required to capture the full diversity of the HD.

However, models commonly use economic and environmental data, because these data are more easily available and accessible, e.g. *catch* and *effort*. Such data are commonly recorded during fishery-independent surveys or as fishery-dependent data for all (large-scale) fleets and markets in the European Union (EU), for example. Economic and environmental considerations are also commonly very prominent in frameworks for a comprehensive approach to fisheries management

(Stephenson et al., 2018). In comparison, consideration of the HD and the collection of HD data has been falling short in the EU compared to collection efforts associated with environmental and economic data and as such social data is often lacking or unavailable (Hatchard & Gray, 2014). Social information is also more difficult to collect as social issues range from individual to global concerns (Bennett et al., 2017), additionally hindering the quantification of HDAs (Hatchard & Gray, 2014; Symes & Phillipson, 2009). In cases where social science data has been provided, information is usually presented in the form of descriptive text, which is often neither read, nor integrated into fisheries assessments in a meaningful way (Hall-Arber, Pomeroy, & Conway, 2009).

In order to ensure that fisheries models can capture the HD and its diversity, multi- and interdisciplinary efforts are needed, with support from various disciplines. Through such efforts, the necessary support for the inclusion and incorporation of the broad concept of HD can be provided. However, it remains unclear to what extend the HD has been integrated into fisheries models and exactly how interdisciplinary the field of HD in fisheries models is at present, and into what areas it should be expanded.

Therefore, the aim of this study is to assess the presence of HD in fisheries models, and to evaluate interdisciplinarity within modelled HDAs. These objectives were translated into the following research questions: *How interdisciplinary is the field of the human dimension in fisheries modelling? Is there a gap between the HDAs that are modelled and those that could be modelled? Are HDAs included in fisheries models modelled in an interdisciplinary manner?*

2 Conceptual Framework

2.1 Interdisciplinarity

In this study, we understand interdisciplinarity as an attempt at mutual interaction between disciplinary components that involves crossing the boundaries of several academic disciplines with contrasting research paradigms in order to create new theories and knowledge (Tress, Tress, & Fry, 2005). Interdisciplinary activities and studies apply, synthesize, integrate, or transcend parts of two or more disciplines with a common goal (Chiu, Kwan, & Liou, 2013; Huutoniemi, Klein, Bruun, & Hukkinen, 2010; Tress et al., 2005). To make the distinction, multidisciplinarity involves several academic disciplines that have multiple parallel goals, often with the purpose of comparison, but does not cross subject boundaries or aim for any form of integration. Transdisciplinarity combines interdisciplinarity with a participatory approach by involving non-academic participants and knowledge bodies to create new knowledge and theory (Tress et al., 2005).

To assess interdisciplinarity within the field of the human dimension in fisheries models, we used the typology and indicators for interdisciplinarity developed by Huutoniemi et al. (Huutoniemi et al., 2010). This typology considers interdisciplinarity on three dimensions: 1. the scope of interdisciplinarity, i.e. what is being integrated; 2. the type of interdisciplinary interaction, i.e. how it is being done; and 3. the types of goals, i.e. why an interdisciplinary approach is being used.

The scope of interdisciplinarity refers to the conceptual and cultural distance between the participating disciplines or research fields. It is understood as *narrow* if the participating fields are conceptually close to each other (e.g. life sciences and biological sciences), whereas it is considered *broad* when the fields are conceptually diverse (e.g. law and engineering). The type of interdisciplinary interaction describes how interdisciplinarity is being carried out, and three different approaches can be distinguished: *empirical*, *methodological*, and *theoretical*. *Empirical* interdisciplinarity integrates different types of empirical data (e.g. qualitative and quantitative data). *Methodological* interdisciplinarity implies the integration of different methodological approaches. As we chose to explore only models as a fisheries research methodology, this dimension of interdisciplinarity has not been assessed in this study. *Theoretical* interdisciplinarity occurs when concepts, models, or theories from more than one field or discipline are synthesized in order to develop new theoretical tools (Huutoniemi et al., 2010). By considering only empirical and theoretical interdisciplinarity, we assumed that the HD should be fit into fisheries models and did not consider potential other methodological approaches that could be suitable for studying fisheries as SECAS and providing science advice to management.

The types of goals can be *epistemologically* oriented to increase knowledge, or *instrumentally* oriented to achieve an extra-academic goal or solve a societal problem. The types of goals can also have a *mixed* orientation when they have both, an epistemological and an instrumental orientation.

3 Methodology

In order to address our research questions, we employed a systematic literature review (SLR) approach that consisted of three consecutive steps: 1. relevant literature was collected and selected in a systematic, reproducible manner; 2. the selected literature was analyzed in a qualitative way through content analysis and hierarchical coding, which was followed by 3. the design of data visualizations. Subsequently, we applied a typology and indicators to assess interdisciplinarity within the data. All the applied methods are explained in detail in the following sections, followed by their limitations.

3.1 Literature collection and selection

In order to select a large enough sample of papers on fisheries models to study the practices being used to the model the human dimension, we decided to use a systematic approach. This provides transparency and replicability and makes the choice of the publications under review comprehensible by determining: 1. a set of keywords to be used as search terms in an unbiased academic search engine, and 2. clear inclusion and exclusion criteria by which the resulting literature will be evaluated. These steps are described in Sections 3.1.1 and 3.1.2.

This methodology is commonly referred to as a Systematic Literature Review (SLR) and is an effective approach for sampling the literature in a systematic and reproducible way. SLRs are commonly applied in fields such as medical science (e.g. Weitzen, Lapane, Toledano, Hume, & Mor, 2004) and software engineering (e.g. Kitchenham et al., 2009), and they are an emerging method in fields such as organisational studies (Maier et al. 2016), education (e.g. Hainey et al. 2016), and marine and coastal studies (e.g. Liquete et al. 2013).

3.1.1 Search terms

The search was conducted using the scientific search engine Scopus (www.scopus.com), where the search terms ‘fisheries’, ‘model*’, and ‘common fisheries policy’ were employed to select for peer-reviewed publications on fisheries models. All subject areas as identified by Scopus (i.e. life sciences, health sciences, physical sciences, social sciences, and humanities) and all possible publication years were selected. The precise search string used in Scopus can be found the Appendix S1. The search was conducted on 25/08/2015.

We used the term ‘fisheries’ in order to select for models with a system perspective, rather than select for models only considering the environmental components (e.g. fish), and therefore we did not use the search term ‘fish*’. To achieve a general perspective on the field of fisheries modelling, we chose not to limit this study to a particular modelling technique (e.g. Bayesian belief networks) or a particular model type (e.g. stock assessment). Thus, we sampled models created for a large variety of fisheries that are performing under similar managerial assumptions. Among the multitude of possible managerial assumptions, we chose the Common Fisheries Policy of the European Union (EU), a common set of rules that applies to all EU fishing fleets and EU fish stocks. This decision was driven mainly by the fact that the EU fisheries are among the most extensively studied in the world (Jarić et al., 2012), therefore presumably offering a large, but still manageable, sample for qualitative analysis. In addition, we considered the source to include a model if the respective item was referred to as a model by the authors of the publication, including qualitative/quantitative models, process/conceptual models, and frameworks.

3.1.2 Inclusion and exclusion criteria

The full text of all publications was downloaded, and the publication metadata was exported from Scopus, including authors, title, year, journal, and journal subject areas. All articles were screened for relevance to the study objectives and included or excluded based on the criteria listed in Table 1.

Throughout this process, we followed the guidelines for systematic reviews in conservation and environmental management (Pullin & Stewart, 2006), and the PRISMA reporting guidelines (Moher, Liberati, Tetzlaff, Altman, & Group, 2009). These guidelines ensure a thorough execution of the sampling and analysis of the literature while carrying out the SLR.

3.2 Content Analysis

The SLR process was followed by a qualitative analysis and synthesis through content analysis, which is a research methodology for making valid inferences from texts in a replicable manner (Krippendorff, 2013). This study followed a problem-driven approach to content analysis, which means that it was motivated by epistemic questions about currently inaccessible information that the text is assumed to be able to answer (Krippendorff, 2013). During our content analysis, coding categories and recording instructions were developed, and an analytical procedure was selected. These steps are explained in detail in Section 3.2.1.

3.2.1 Coding of the human dimension aspects

The content of the selected publications, i.e. the information relevant to the research questions of this study, was analysed through coding and the development of a category system. Coding is the process of categorising and organising information into a meaningful framework (Johnson, 2007) to empower and speed up systematic qualitative data analysis (Lofland, Snow, Anderson, & Lofland, 2006). The term coding refers to the process of reading the data and dividing it into meaningful analytical units, also known as segmenting the data. Once a meaningful unit has been identified, it is coded, which means that the unit is marked with a descriptive word or a category name. During coding, a master list is maintained in order to keep track of all previously coded units, so that codes can be reapplied to new data segments each time an appropriate unit or segment is discovered within the text (Johnson, 2007). We developed an indicative code, which means that it was created by the researcher whilst directly inspecting the data, in contrast to, for example, using a pre-existing set of codes that had been developed *a priori* to the analysis.

We coded the data according to a hierarchical category system. This enables organisation of the data into different levels or categories based on the idea that some themes are more general than others, and that codes are therefore related vertically (Johnson, 2007). We used the term 'function' to describe the categorical relationship between the codes. A functional relationship between two variables essentially means: *X is used for Y* (Johnson, 2007).

In the code developed for this study the main aspect modelled by a publication, or the main subject of the model, was coded as the first hierarchical unit representing the general theme and overall goal. The main aspect modelled was identified based on what the authors themselves stated in the title, the abstract, or the introduction to the article (e.g. "…we modelled the exploitation of a fishery…"). The theme identified as the overall goal or main aspect of the model was categorised into one of three dimensions: human/social, economic, or environmental, or a combination of these (see Section 3.2.2).

Studies whose main aspect was identified as the human dimension were analysed in depth via further hierarchical coding to determine through which variables they had been modelled. Two more descending hierarchies were introduced into the coding, which resulted in a three-level code hierarchy: Level 1—the main HDA; Level 2—variables that were used to model Level 1 and the functional relationship between them; Level 3—variables that were employed to model Level 2 and the functional relationship between them. In more mathematical terms, this can be described as follows:

$$HDA = \mathrm{F}\,(b, c)\,, \qquad \text{with } b = \mathrm{G}\,(d, e)$$

where HDA is the main HDA, (Level 1), which is modelled as a function F of the variables b and c, and where b is modelled as a function G of the variables d and e.

All these variables were coded in NVivo 11 (QSR International Pty Ltd, 2015). The codes, which are represented as nodes in NVivo, were assigned to hierarchical categories in order to distinguish between Level 1, Level 2, and Level 3 variables (Figure 1).

In addition, information on the modelling techniques and types e.g. Bayesian belief network, bioeconomic model, etc., were extracted from the publications and recorded in Microsoft Excel 2016.

3.2.2 Assigning the dimensions identified in the fisheries models to the human dimension aspects

The identified HDAs and other variables were assigned to the dimensions described previously (*human/social*, *economic*, and *environmental*) based on the indicators for sustainable development of marine capture fisheries developed by the Food and Agriculture Organization (FAO) of the United Nations (see Section 2.3. Table 3 in FAO Fishery Resources Division, 1999). We included the FAO's *governance* dimension in the *social* one and renamed the latter as the *human* dimension. The *economic* dimension was treated as a dimension in its own right, as the tradition of treating it separately in fisheries science seems to be very strong (Haapasaari, Kulmala, & Kuikka, 2012). We found the FAO framework appropriate given its global penetration level and authority in fisheries science, but we are aware that other categorizations and divisions of fisheries systems exist (A. Charles, 2000). The human dimension aspects were categorized into three topics as described by Bennett et al. (2017): *social phenomena*, *social processes*, and *individual attributes*.

3.2.3 Enumeration of the qualitative data

The qualitative coding analysis of the publications was followed by enumeration, which refers to the quantification of the qualitative data and coding results, for example, the number of HDAs and the human/social, economic, and environmental variables for each HDA were counted. The enumeration of the qualitative data was conducted using the software NVivo 11 (QSR International Pty Ltd, 2015) because computer-aided qualitative data analysis allows for the automated enumeration while enabling all data to be exported into other formats (e.g. csv, excel, etc.).

3.3 Visualizations of the human dimension aspects

The creation and use of displays (i.e. visualisations—the organised, compressed assembly of information that permits the drawing of conclusions and subsequent actions) is an important part of qualitative data analysis (Miles & Huberman, 1994). In order to be able to design relevant visualisations for this study, the qualitative data (i.e. the HDAs and their corresponding variables) were exported from NVivo 11 to Microsoft Excel 2016. They were transformed using Python into a data format (source-to-target) adequate for import into Gephi (Version 0.9.1), which is an open source visualisation tool for graph and network analysis (Bastian, Heymann, & Jacomy, 2009). This program allows for visual analytics and functions as a complementary tool to perform enumeration, to enable visual thinking, and to facilitate reasoning. In particular, Gephi was used for qualitative and quantitative visualisation of the hierarchy and the connections between the HDAs and the variables, as shown in Figure 1.

To give a qualitative representation of how the HDAs were modelled, the HDAs and variables were represented as nodes and the connections between them as edges, while the colour of each node was set according to the dimension that was assigned to the variable. The colours were assigned as follows: pink: human; blue: economic; green: environmental; white: other (e.g. time) or more than one dimension (e.g. sustainability). To include a quantitative representation of the results, the size of the nodes was set according to the publication count (i.e. the overall number of sources that featured this variable), which gives an impression of the relative importance of each. Each HDA in the study was treated separately, and a visual representation was created for each. The network algorithm used in Gephi was ForceAtlas2 (Jacomy, Venturini, Heymann, & Bastian, 2014).

3.4 Assessment of interdisciplinarity

Interdisciplinarity was assessed based on the typology and indicators described by Huutoniemi et al. (2010), as explained in Section 2. We assessed interdisciplinarity in the modelling of the human dimension in fisheries through: 1. indicators of the scope of interdisciplinarity (narrow or broad, i.e. what is being integrated), and we assessed interdisciplinarity within the modelled HDAs through 2. the types of interdisciplinary interaction (empirical or theoretical, i.e. how the integration is done). The former was determined by an inspection of the diversity of the journals in which the papers were published, and their subject areas, and as well as the diversity of the types of models. The latter was determined by inspecting the diversity of the HDAs found within the models (theoretical interdisciplinarity), and examining the diversity of the fisheries dimensions (human, economic, environmental) within the variables used to model the HDAs (empirical interdisciplinarity). It is important to emphasize that we assessed the interdisciplinarity of the sample as a whole (based on the aggregated empirical data we had collected), rather than looking at each individual model separately.

We did not asses the types of goals because this was not the primary purpose of our study.

3.5 Limitations of the applied methodology

One limitation of the SLR approach, as with any keyword-based study, is that the choice of keywords is prone to human subjectivity, and that relevant literature can be potentially excluded if the keywords are not present in the searchable fields, e.g. abstract, title, or keywords of the item. Also, the similar managerial assumptions introduced through the keyword search of "common fisheries policy" might not necessarily encourage the incorporation of the HD into fisheries models, and are as such a limitation of this study. Additionally, the number of publications reviewed is often much smaller than in, for example, computational approaches such as topic modelling (Syed & Weber, 2018).

Another limitation of the SLR approach is the exclusion of grey literature. Grey literature is not indexed in the same manner as scientific publications, and therefore cannot be sampled in the same way. On the other hand, grey literature does not undergo the same rigorous peer-review process as scientific journal publications, which gave us a good enough reason to exclude it and focus our interest on peer-reviewed scientific publications. We are aware that due to the limitations of this approach, relevant documents might have been excluded and are therefore absent from our sample. As such, our work reflects the academic contributions to the incorporation of HD into fisheries models, but not the fisheries science contributions as a whole (including modelling of stock assessments and advice) to this domain. However, since the aim of this study was to select a large sample of the literature in a transparent manner, rather than to identify all of the literature in the field, the methodological approach described above was considered sufficient.

Another limitation of the SLR approach is inherent to qualitative analysis and synthesis: it is an interpretative process, and the results can vary between human coders. Therefore, to ensure coding consistency, the coding was conducted by only one of the authors.

Interdisciplinarity is difficult to assess (Huutoniemi et al., 2010) and the approach applied here is therefore another limitation of this study. The measures used to assess interdisciplinarity (journal subject areas, model diversity, human dimension categories, and diversity of variables used to model the human dimension) are indicators and thus not direct measures of interdisciplinarity because they do not measure actual integration. This is due to the fact that the exact form and degree of integration in interdisciplinary research is often difficult to identify within a publication if it is not made explicit (e.g. whether the theories underlying the model were integrated and which theories they were). However, we assume interdisciplinarity (and not multidisciplinarity) because the HDAs are modelled in individual models and as such, various variables and data were integrated into the model to achieve the overall goal of modelling the HDA (instead of achieving multiple parallel goals).

4 Results and Discussion

4.1 How interdisciplinary is the field of modelling the human dimension?

The Scopus search generated a total of 211 publications, out of which 131 were excluded based on the inclusion and exclusion criteria in Table 1. This left 80 publications that were eligible for further qualitative analysis. Within these 80 publications, we identified 31 papers as modelling an HDA, based on our coding criteria of the content analysis (see Appendix S3 for a full list of these papers). These 31 articles had been published in 20 different journals, which were listed in eight different subject areas in Scopus (Table 2). While some of the subject areas can be considered relatively similar from a conceptual point of view (e.g. *environmental sciences* and *agricultural* and *biological sciences*), other subject areas were conceptually diverse and crossed the boundaries of broad intellectual areas (e.g. *social science* and *computer science*). At the same time, many of these journals were registered in more than one field (e.g. *Marine Policy* is listed in three fields, *Land Economics* is listed in two fields). This spread of journals and subject areas, together with the presence of the same journals in multiple fields, could indicate the potential for both narrow and broad interdisciplinarity in the modelling of the human dimension in fisheries. At the same time, it is interesting to note that, even though the models we analysed were about the human dimension, and one would expect these to be published mainly in journals in the field of social sciences, the most highly-represented subject field was environmental science, with social sciences being only half the size. This result is in line with the fact that fisheries science has been traditionally dominated by natural scientists (Link, 2010).

The journal with the highest frequency of appearance in the dataset was *Marine Policy*, accounting for almost one third of the articles on modelling an HDA in fisheries. This is not surprising, considering that the journal describes its contributions as a "*unique combination of analyses in the principal social science disciplines relevant to the formulation of marine policy*" (Elsevier, 2018), while the main topics published by this journal are fisheries management, conservation, fishing gear, and models (Syed et al., 2018).

A total of 36 different model types were identified within the publications, ranging from classic economics models (e.g. econometrics models) to theoretical frameworks (Table 3). As is the case for publication outlets and subject areas, this spread of model types could indicate the potential for both narrow and broad interdisciplinarity in the field being analysed. The application of various modelling approaches could be a potential first step towards an integration of the human dimension into fisheries assessments (Schlüter et al., 2012).

Almost one fifth of the publications included in this analysis used a bioeconomic model. The greater use of these models is likely related to their long-term use in fisheries, dating back to Gordon (1954) and Clark (1973). It might also indicate the interdisciplinary practice of borrowing methods and tools from across the disciplines in an effort to address the needs dictated by the specific problem at hand (Huutoniemi et al., 2010). It is also possible that the uptake of models more suitable for modelling the human dimension, e.g. agent-based models (Schlüter et al., 2012), and social network analysis (Scott, 2017), is rather slow.

4.2 Is there a gap between the human dimension aspects that are modelled and those that could be modelled?

A total of 20 different main HDAs (Table 4) were identified within the 31 publications. These aspects cover all three of the categories of topics relating to the human dimension described by Bennett et al. (2017), which could be taken as a sign of theoretical interdisciplinarity at the field level. However, the number of specific aspects that have been modelled is rather small compared with the wealth of HDAs that could be modelled. As stated in Syed et al. (2018), the human dimension in fisheries in particular, or in any similar social-ecological sytem in general, could be explored by addressing topics such as: "institutional aspects (enforcement and compliance, policy interactions etc.), social aspects (gender, religion/beliefs, welfare, social cohesion, social networks, education and learning, human agency, health, safety and security at sea, food security, perception, attitudes, social norms, compliance, mental models of various actors involved in fisheries etc.), economic aspects (poverty, innovation, distribution of benefits, spiritual, inspirational, and aesthetic services of fisheries etc.), political aspects (power structures, transparency etc.), and cultural aspects (traditional/local ecological knowledge, history, cultural dimensions, culinary choices, heritage, blue humanities, fisheries literacy etc.)". Note that this list is not exhaustive and the items are listed in random order.

Comparing this list with the results of this study, there appears to be a wide and obvious gap between the HDAs that are modelled and the ones that could be modelled. However, considering our sample size of 31 papers, this gap exists only within the context explored by this review and does not necessarily reflect the situation in the Common Fisheries Policy area.

A theory describes our understanding of the components and aspects of reality, and their interactions. Once developed, a theory guides modellers in their decisions regarding what elements, relationships, and processes to include into their models. It is therefore the case that a model itself and the generalizability of its results can be judged by the validity and quality of the theories incorporated (Raser, 1972). Moreover, when studying complex systems, a single theory taken in isolation is rarely sufficient (Orcutt, Greenberger, Korbel, & Rivlin, 1961). From this perspective, achieving theoretical interdisciplinarity is a pre-requisite for integrative theories and/or theories from more than one field, assuming that these theories are suitable for integration. The low amount of HDAs in our systematic literature review might indicate a shortage of adequate theories or data in the context of fisheries, as particularly data (or their lack) are often a limiting factor.

4.3 Are human dimension aspects modelled in an interdisciplinary manner?

The 20 Level 1 HDAs were modelled through a total of 43 different Level 2 variables and 137 different Level 3 variables (see Appendix S4 and S5.). All visual representations of the HAD are presented in Figure 3 and in Appendix S6. *Perception and views* has the most Level 2 variables. *Fish auctions* has the smallest number of Level 3 variables, with only three (Figure 3), whereas *socio-bio-economic consequences* has the largest number of Level 3 variables, with 37. *Fish auctions* also has the smallest number of variables overall, with a total of five across Level 2 and Level 3. Other HDAs with generally low numbers of Level 2 and Level 3 variables are *fisheries dependency* (n=6) and *decision making* (n=6). The majority of the HDAs have a total number of variables between 10 and 20. The HDA *socio-bio-economic consequences* has the largest number of variables overall, with a total of 41. This variety of Level 2 and Level 3 variables might indicate the existence of several theories around the same aspect of Level 1, something which contributes to theoretical interdisciplinarity of the field.

The number of aspects modelled and the variables assigned to each dimension are shown in Figure 2. A close inspection of this figure reveals that the proportion of each of the three fisheries dimensions changes with an increase in the depth of analysis. Thus, at Level 2, the count and usage of human dimension variables are higher, compared to the environmental variables. Whereas at Level 3, human dimension variables' usages is much lower compared to economic variables' usage. This diversification might indicate an empirical interdisciplinary nature to the modelling of the human dimension. However, it might also indicate a lack of suitable operationalisation of human dimension variables and, consequently, a lack of suitable data to use in modelling. At the same time, this highlights how the human dimension can be modelled through economic and environmental variables, and the entanglement of the dimensions.

Only one HDA, *governance,* was modelled entirely through human dimension variables on all levels. *Fish auctions* was the only HDA where all Level 2 and Level 3 factors were economic (Figure 3). The two HDAs *fishing strategy* and *institutional inertia* were modelled through Level 2 and Level 3 variables from only two different dimensions, whereas *fishing strategy* was modelled through factors from the *economic* and *environmental* dimensions, and *institutional inertia* was modelled through factors from the *economic* and *human* dimensions (see Appendix S6). Thirteen HDAs were modelled through Level 2 and Level 3 variables from three different dimensions (n=12) and five HDAs were modelled through Level 2 and Level 3 variables from all dimensions. These were: *socio-bio-economic consequences, compliance*, *evaluation of management plans*, *perception and views*, and *TAC setting process*.

Overall, variables from the *economic* dimension were used the most often (Figure 2); in particular, *cost* (n=13), *effort* (n=13), and *price* (n=12) were the most used *economic* variables in Level 3. The variables from the *human* dimension that were used most often in Level 3 were *demography* (n=4), *regulation* (n=4), and *employment* (n=3), whereas the most frequently used variables from the *environmental* dimension in Level 3 were *stock* (n=13), *area* (n=6), and *fishing mortality* (n=4). This study suggests that HDAs are mainly modelled through economic and partly through environmental variables, which represents the data typically available for fisheries assessments. Some of the social aspects, such as *governance*, might be very difficult (if not maybe impossible) to be expressed in numerical terms.

4.4 How to advance the interdisciplinarity of the field

As a first step to advance the interdisciplinarity of the field, we suggest a protocol based on Huutoniemi et al. (2010) that succinctly describes the elements necessary for assessing various interdisciplinary typologies, shown in Table 5. Such a protocol could guide scientists on how to take an interdisciplinary approach during model development and implementation. It is also paramount for the advancement of the field that human dimension models are reproducible. Many of the descriptions of models in published articles are incomplete, which makes it impossible to re-implement them or replicate their results (Railsback & Grimm, 2012). As we have ourselves encountered when carrying out this study, model descriptions are often "a wordy mixture of factual descriptions and lengthy justifications, explanations, and discussions of all kinds" (Railsback & Grimm, 2012). Therefore, we also suggest that this protocol is used as a documentation tool in order to help modellers to express the interdisciplinary characteristics of their models clearly. This would also aid model communication, in-depth model comprehension, model assessment, model replication, model comparison, theory building, and code generation (Müller et al., 2014).

Social issues are often complex and understanding these issues from a fisheries management perspective will require interdisciplinary efforts from the natural and social sciences, as well as the humanities (Urquhart, Acott, Symes, & Zhao, 2014). This assertion is backed by this empirical study, which brings evidence on how entangled the human dimension is when viewing fisheries as SECAS. Multi- and interdisciplinarity would entail the transfer of knowledge, tools, and methods from a multitude of disciplines into the field of fisheries science, making it possible to integrate various data inputs (e.g. quantitative and qualitative data). Existing methods, such as agent-based models, systems analysis, and social network analysis from domains ranging from political science to business organisation could be integrated into fisheries science and used to study societies, social interactions, and people's behaviour in fisheries (Libre et al., 2015; Scott, 2017).

Through an expansion of current practices, a wider range of the HDAs could be considered in fisheries models to better reflect the diversity of the human dimension. This endeavour could be fostered further through the inclusion of scientists from the social sciences and the humanities right from the start of a project (Criddle, 2016). In this way, they can contribute to the formulation of the research questions that ought to be answered by a model, which could lead to a more diversified investigation of the human dimension.

The challenges of performing interdsiciplinary research are not new, as they have been alredy identified 20 years ago (see for example Volume 2, Issue 4, 1999 of the journal Ecosystems).Thus, in order to address the issues identified by the above analysis, it might be that fisheries science will require new types of experts, besides biologists, mathematicians, and statisticians: 1. scientists from the social sciences and the humanities; 2. scientists with interdisciplinary backgrounds who can address fisheries from a more holistic perspective and apply the concept of SECAS to multi- and interdisciplinary fisheries workgroups and research; and 3. modellers with the latest skillset who are trained to use tools that can reflect fisheries as SECAS, and include the human dimension in an interdisciplinary way. This would potentially lead to the rise and also the recognition of a new kind of natural resources expert: interdisciplinary individuals with the flexibility required to move between fields and explore various SECAS, e.g. sustainability science (Haider et al., 2018), conservation science, and complexity science.

Researchers putting aside their differences and finding better ways to communicate could support the practice of interdisciplinary science and disciplinary cross-fertilisation (Arlinghaus, Hunt, Post, & Allen, 2014), whilst the interdisciplinary development of conceptual models could support communication between social and natural scientists (Hall-Arber et al., 2009). Some things in the culture of science might have to change, e.g. arrogances and the way we speak to each other, but we also need to rethink our assumptions, values, and institutional structures (Degnbol et al., 2006). Researchers from cross-disciplinary research programs, as well as innovative graduate training programs, would have to become more involved. In addition, interdisciplinary career choices would have to be rewarded instead of generating a fear of risking one's career (Fischer et al., 2012; Rhoten & Parker, 2004).

Besides experts and scientists from different disciplines, the insight of stakeholders should also be taken into account. Stakeholders and practitioners, such as management authorities and non-governmental organisations, can contribute to the modelling process through co-creation (Santiago et al., 2015; Wood, Stillman, & Goss-Custard, 2015). Co-creation could highlight the importance of HD components and lead to assurances that managers and policy makers will take the behaviour of individuals and organisations into consideration within their fishing communities. As such, this would make models of the human dimension more relevant for management and decision making, while supporting local and global policies and goals, such as the EU's Common Fisheries Policy and the United Nations' Sustainable Development Goals (United Nations, 2015).

Furthermore, with this study we wish to stimulate the discussion on how best to model the human dimension of SECAS. As it currently stands, based on our empirical results, the human dimension is largely modelled through economic and environmental variables. One could argue that the field of human dimension modelling needs more operationalisable social theories and more data relevant to these theories. At the same time, using more easily available economic and environmental data is a more practical short-term approach. In contrast, some argue for extreme caution in modelling the human dimension, and social phenomena in general (ní Aodha & Edmonds, 2017). These decisions will likely be made on an individual level, but we hope that researchers from all fields can engage in these discussions and share their experiences as well as the reasons for the approaches they have taken and their lessons learned.

5 Conclusions

This study identifies a variety of HDAs that have been investigated in the context of fisheries models. There is broad potential for the expansion of the human dimension in fisheries models. This expansion is important in order to increase our understanding of fisheries systems in general, and to better reflect the interdisciplinarity of the field in order to support sustainable fisheries management.

In the support of modelling the human dimension in a SECAS context, interdisciplinary approaches are required. Such efforts need to focus on several aspects, including: acknowledging that exploring the human dimension requires interdisciplinarity; early involvement of all relevant disciplines and stakeholders in model development through co-creation; improved development and integration of tools for the modelling of HDAs; the formulation of operationalisable theories and the collection and inclusion of more data from the human dimension. To further improve and advance the interdisciplinarity of human dimension modelling in the long term, model transparency, documentation, and communication will be key. A model publication should be easy for the reader to understand and follow, and it should make the HDAs and levels of interdisciplinarity explicit. Clear model descriptions will enable interested readers and modellers to understand how interdisciplinarity and human dimension modelling was achieved, thus facilitating model uptake and re-use by scientists, managers, and policy makers.

6 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

7 Author Contributions

CW collected and analyzed the data. CW and MB interpreted the data. CW, MB, and MA wrote the manuscript.

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10 Supplementary Material

The Scopus search string (Appendix S1), the PRISMA flow diagram (Appendix S2), a table listing all publications included in analysis and synthesis phase (Appendix S3), a table for all Level 2 variables (Appendix S4), a table for all Level 3 variables (Appendix S5), and all remaining visualisations (Appendix S6) are available in the Supplementary Material.

1 Data Availability Statement

The list of publications analyzed in this study can be found in the Supplementary Material.

Table 1. Inclusion criteria used to select publications for the systematic literature review of modelling the human dimension in fisheries models.

Inclusion criteria	Why this criterion
Published in the English language.	English is by far the most common language for scientific publications in this field.
Study/research published in a scientific journal or conference paper.	Articles in scientific journals have undergone rigorous quality controls and conference proceedings are published more often and much more quickly than articles.
Refers to a fisheries model.[1]	Our study focuses on models pertaining to fisheries.
Refers to the Common Fisheries Policy.	Our study focuses on studies connected to this set of rules for managing European Union fishing fleets and for conserving European Union fish stocks.
Contains the words ‘human dimension’, ‘social’, or ‘socio*’ within the body of the full text.[2]	Our study focuses on articles connected to the human dimension of fisheries.
Models a human dimension aspect of fisheries.	Our study focuses on the human dimension.

[1]We considered it to be a model if it was referred to as ‘model’ by the authors of the publication.
[2]We included the words ‘social’ and ‘socio*’ because ‘human dimension’ is a relatively new term in fisheries and might not be included as such in older publications.

Table 2. The subject areas and corresponding journals identified in this study. Subject areas are labelled as indicated by Scopus. *Count* refers to the number of articles found in each subject area. *Journal (count)* refers to the journal title and the number of articles from our study found within that journal (shown in parentheses after the journal name). Numbers are only indicated if there was more than one article per journal. Note that several journals are included in more than one subject area.

Count	Subject Areas (as indicated by Scopus)	Journal (count)
21	Environmental Sciences	Ambio Ecological Modelling Fish and Fisheries Human Ecology ICES Journal of Marine Science (3) Journal of Institutional and Theoretical Economics Land Economics Marine Ecology Progress Series Marine Policy (9) Methods in Ecology and Evolution Ocean and Coastal Management
20	Agricultural and Biological Sciences	Canadian Journal of Fisheries and Aquatic Sciences Ecological Modelling Ecology and Society Fish and Fisheries Fisheries Management and Ecology Fisheries Research ICES Journal of Marine Science (3) Journal of Fish Biology Marine Ecology Progress Series Marine Policy (9) Methods in Ecology and Evolution Ocean and Coastal Management
14	Economics, Econometrics and Finance	Applied Economics

		Journal of Institutional and Theoretical Economics
		Land Economics
		Marine Policy (9)
		Panoeconomicus
12	Social Sciences	Ambio
		Human Ecology
		International Journal of the Commons
		Marine Policy (9)
5	Earth and Planetary Sciences	ICES Journal of Marine Science (2)
		Fish and Fisheries
		Ocean and Coastal Management
		Ecology and Society
1	Decision Sciences	International Transactions in Operational Research
1	Computer Science	International Transactions in Operational Research
1	Business, Management and Accounting	International Transactions in Operational Research

Table 3. Model types extracted from the publications in this study, sorted alphabetically. Counts of each model type are indicated in parentheses if there was more than one occurrence.

Model Types

- 3-Dimensional Wellbeing Framework
- Accessibility Analysis
- Age-Structured Model
- Allocation Management Model
- Bayesian Approach in Participatory Modelling
- Bayesian Belief Network (BBN) (n=3)
- Binary Logit Model
- Bioeconomic Model (n=6)
- Conditional Logit Model (n=2)
- Decision Making Model (Single-Species)
- Discrete Choice Random Utility Model (RUM) (n=2)
- Dynamic State Variable Model (DSVM) (IBM)
- Econometric Model
- Flow Chart
- Game Theoretical Model
- Generalised Additive Model (GAM)
- Generalised Linear Model (GLM)
- Gravity Model
- Individual-Based Model (IBM)
- Linear Model
- Logistic/Ordered Regression Model (n=3)
- Management Evaluation Framework
- Management Scenario Model
- Management Strategy Evaluation Model/Approach (MSE)
- Market-Orientated Value-Adding (MOVA) Management Model
- Multinomial Logit Model
- Press Perturbation Analysis
- Principal Agent Model
- Qualitative Model Analysis
- Socio-Bio-Economic Model
- Statistical Analysis
- Statistical Model
- System Dynamics Model
- Theoretical (Framework) Model of Governance Architecture
- Theoretical Institutional Model (n=2)
- Theoretical Model of An Evaluation Framework for Fisheries Resource

Table 4. List of human dimension aspect (HDAs) identified within the publications, mapped against the general human dimension topics of study proposed by Bennett et al. (2017) . Count is the number of publications that model the HDA.

Human Dimension Category (Total count)	HDA (Level 1)	Count
Social phenomena (8)	Fisheries Dependency	1
	Governance	1
	Institutional Inertia	1
	Regulation	2
	Socio-Bio-Economic Consequences	3
Social processes (15)	Commitment	2
	Compliance	3
	Decision Making	1
	Effort Allocation	3
	Enforcement	2
	Evaluation of Management Plans	2
	Fish Auctions	1
	Total Allowable Catch Setting Process	1
Individual attributes (11)	Enter and Exit the Fishery	2
	Fishing Strategy	1
	Métier Selection	1
	Over-Quota Discarding	1
	Perception and Views	4
	Switching of Métiers	1
	Wellbeing	1

Table 5. An overview of the protocol for assessing the interdisciplinarity of models, based on Huutoniemi et al. (2010).

What	**Scope of Interdisciplinarity**	**Narrow**	**Broad**	
		What disciplines and knowledge bodies were involved and integrated, e.g. what disciplines contributed to this model, what stakeholders added knowledge to the concept of the model etc.		
How	**Type of Interdisciplinarity**	**Empirical**	**Methodological**	**Theoretical**
		Which types of data and data sources (knowledge bodies) were included (e.g. social, economic, environmental; qualitative data, quantitative data, academic data, non-academic data from stakeholders/local ecological knowledge etc.)?	*Which different modelling tools/methods were integrated? Is this a new integrative modelling method involving different stakeholders (e.g. participatory modelling)? How was integration achieved?*	*Which theories were used and integrated (e.g. which social theories were used?)?*
Why	**Goal of interdisciplinarity**	**Epistemological**	**Instrumental**	
		The production of new understanding and knowledge. (Why do we need this understanding? What is the new knowledge for?).	*To solve a problem or a societal challenge (What is the problem the model is trying to solve?)*	

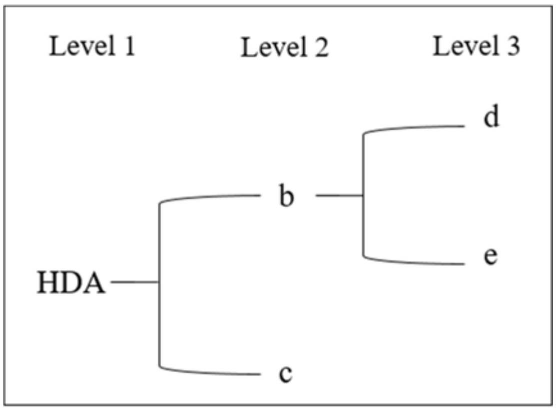


Figure 1: A conceptual display of the hierarchy of variables used to model the main Human Dimension Aspects (HDA) of the human dimension fisheries models. Level 1 represents the main HDA, and Levels 2 and 3 represent the variables (b,c and d,e) that were used in a functional relationship to model the HDA.

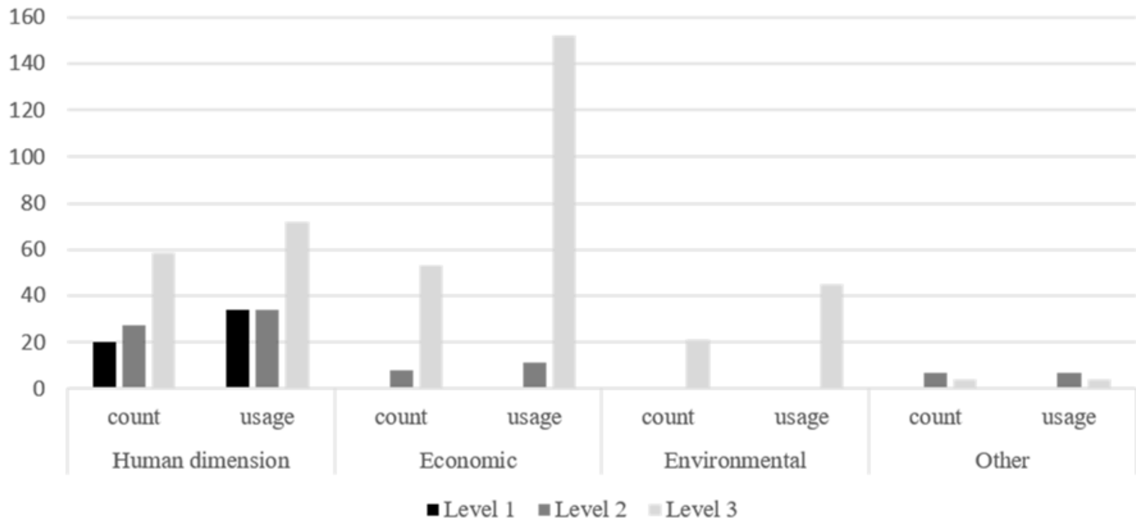


Figure 2. Occurrence and usage of Human Dimension Aspects (HDAs) for all three levels of variables. Count indicates the number of different aspects identified for each level and each dimension. Usage indicates the number of times that aspects/variables from each dimension were used. Other includes variables that could not be categorized within the three dimensions, human, economic, and environmental, such as time.

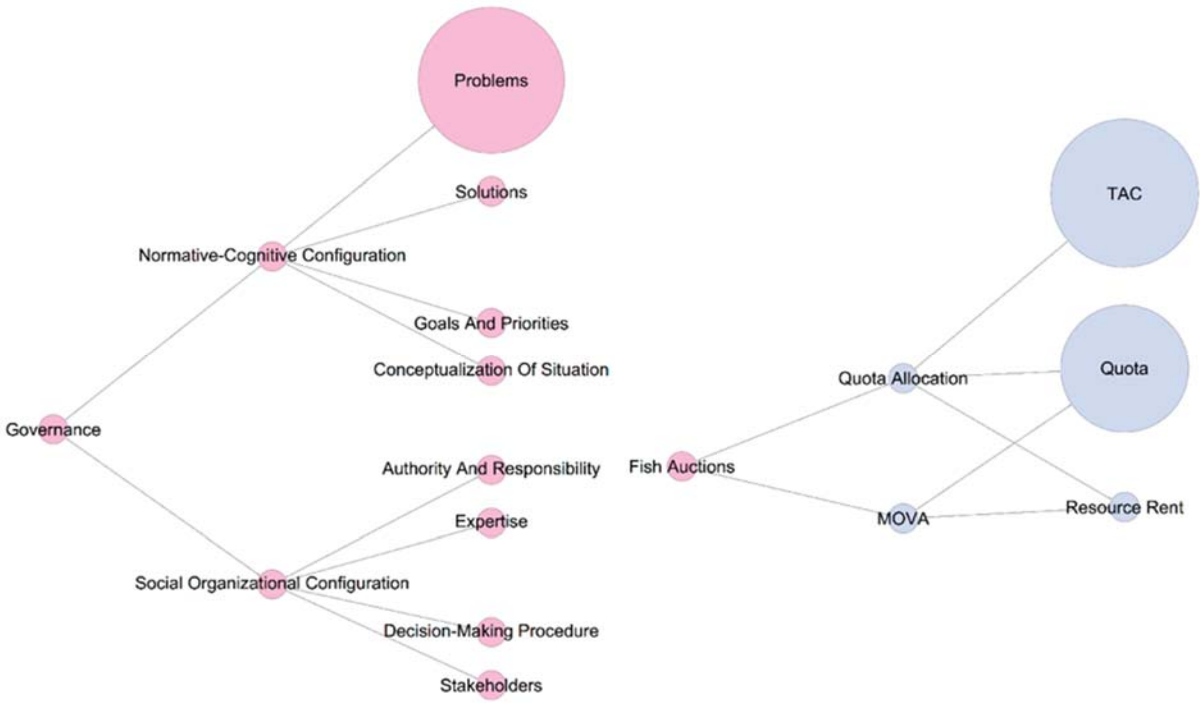


Figure 3. A visual representation of the Human Dimension Aspects (HDAs) governance (left) and fish auctions (right) and the Level 2 and Level 3 variables that were used to model these social aspects. The size of each node represents the relative importance of the variable (i.e. the number of publications using it) and the color indicates its dimension (pink: human; blue: economic; green: environmental; white: other/more than one dimension). The position of each node (left – middle – right) indicates its level (Level 1 – Level 2 – Level 3).

Supplementary Material

An Interdisciplinary Insight into the Human Dimension in Fisheries Models. A Systematic Literature Review in a European Union Context.

Charlotte Teresa Weber*, Melania Borit, Michaela Aschan

*** Correspondence:** Charlotte Teresa Weber: charlotte.t.weber@uit.no

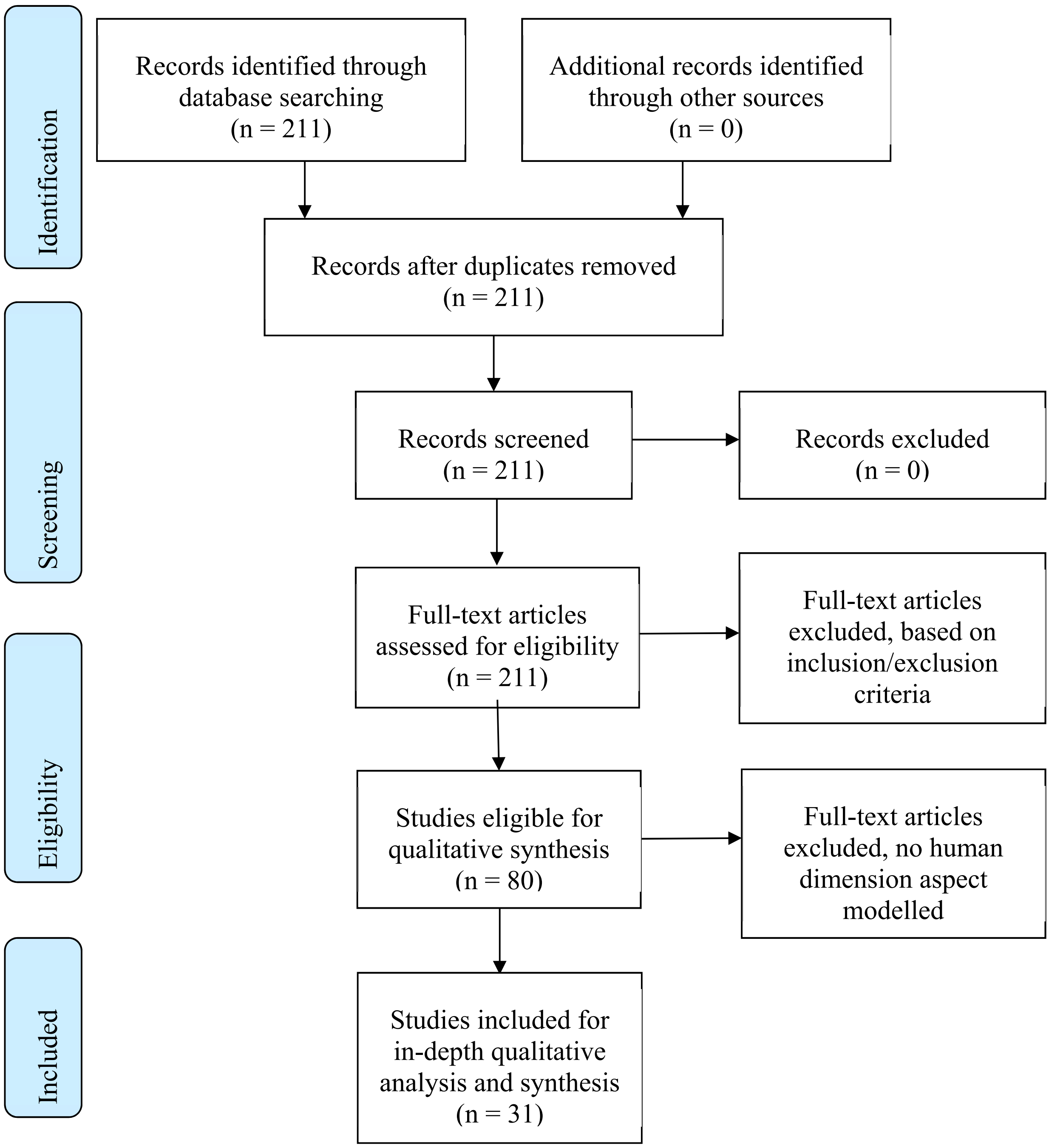
1 Appendix S1.

Scopus Search String:

(TITLE-ABS-KEY(fisheries) AND TITLE-ABS-KEY(model)AND ALL("Common Fisheries Policy")) AND (LIMIT-TO(LANGUAGE,"English")) AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"cp"))*

Appendix S2.

PRISMA Flow Diagram, adapted from (Moher et al., 2009), containing all steps and short explanations for the process of document exclusion during the process of selecting the publications suitable for analysis.



3 Appendix S3.

List of all publications included in the analysis and synthesis phase. In alphabetical order based on first author.

Authors	Title	Year	Journal
Aanesen, M; Armstrong, C	Stakeholder influence and optimal regulations: A common-agency analysis of ecosystem-based fisheries regulations	2013	Journal of Institutional and Theoretical
Aanesen, M; Armstrong, C W	The implications of environmental NGO involvement in fisheries management	2014	Land Economics
Amigo-Dobaño, Lucy; Dolores Garza-Gil, M.; Varela-Lafuente, Manuel	The perceptions of fisheries management options by Spain's Atlantic fishermen	2012	Marine Policy
Andersen, B S; Ulrich, C; Eigaard, O R; Christensen, A S	Short-term choice behaviour in a mixed fishery: Investigating métier selection in the Danish gillnet fishery	2012	ICES Journal of Marine Science
Astorkiza, K; del Valle, I	Changing the total allowable catch (TAC) decision-making framework: A central bank of fishes?	2013	Panoeconomicus
Bastardie, Francois; Nielsen, J Rasmus; Miethe, Tanja	DISPLACE: a dynamic, individual-based model for spatial fishing planning and effort displacement — integrating underlying fish population models	2014	Canadian Journal of Fisheries and Aquatic
Batsleer, J; Poos, J J; Marchal, P; Vermard, Y; Rijnsdorp, A D	Mixed fisheries management: Protecting the weakest link	2013	Marine Ecology Progress Series
Britton, E; Coulthard, S	Assessing the social wellbeing of Northern Ireland's fishing society using a three-dimensional approach	2013	Marine Policy
Burns, T R; Stöhr, C	Power, knowledge, and conflict in the shaping of commons governance. The case of EU Baltic fisheries	2011	International Journal of the Commons

Da Rocha, J M; Cerviño, S; Villasante, S	The Common Fisheries Policy: An enforcement problem	2012	Marine Policy
Da Rocha, J M; Villasante, S; González, R T	Credible enforcement policies under illegal fishing: Does individual transferable quotas induce to reduce the gap between approved and proposed allowable catches?	2013	Ambio
Gezelius, S S; Raakjær, J; Hegland, T J	Reform drivers and reform obstacles in natural resource management: The Northeast Atlantic fisheries from 1945 to the present	2010	Human Ecology
Haapasaari, P; Michielsens, C G J; Karjalainen, T P;	Management measures and fishers' commitment to sustainable exploitation: A case study of Atlantic salmon fisheries in the Baltic Sea	2007	ICES Journal of Marine Science
Haapasaari, P; Mäntyniemi, S; Kuikka, S	Baltic herring fisheries management: Stakeholder views to frame the problem	2012	Ecology and Society
Hatcher, A; Jaffry, S; Thebaud, O; Bennett, E	Normative and social influences affecting compliance with fishery regulations	2000	Land Economics
Jensen, C L; Aarset, B	Explaining noncompliance in the Norwegian coastal cod fishery: An application of the multinomial logit	2008	Applied Economics
Levontin, P; Kulmala, S; Haapasaari, P; Kuikka, S	Integration of biological, economic, and sociological knowledge by Bayesian belief networks: The interdisciplinary evaluation of potential management plans for Baltic salmon	2011	ICES Journal of Marine Science
Martins, J H; Camanho, A S; Oliveira, M M; Gaspar, M B	A system dynamics model to support the management of artisanal dredge fisheries in the south coast of Portugal	2015	International Transactions in
McCausland, W D; Mente, E; Pierce, G J; Theodossiou,	A simulation model of sustainability of coastal communities: Aquaculture, fishing, environment and labour markets	2006	Ecological Modelling
Miethe, T; Bastardie, F; von Dorrien, C; Nielsen, J R	Impact assessment of a fisheries closure with effort and landings spatial analyses: A case study in the Western Baltic Sea	2014	Fisheries Research

Natale, F; Carvalho, N; Harrop, M; Guillen, J;	Identifying fisheries dependent communities in EU coastal areas	2013	Marine Policy
Nielsen, K N; Holm, P	A brief catalogue of failures: Framing evaluation and learning in fisheries resource management	2007	Marine Policy
Parés, C; Dresdner, J; Salgado, H	Who should set the total allowable catch? Social preferences and legitimacy in fisheries management institutions	2015	Marine Policy
Pita, C; Pierce, G J; Theodossiou, I	Stakeholders' participation in the fisheries management decision-making process: Fishers' perceptions of participation	2010	Marine Policy
Pita, C; Theodossiou, I; Pierce, G J	The perceptions of Scottish inshore fishers about marine protected areas	2013	Marine Policy
Rätz, H J; Charef, A; Abella, A J; Colloca, F; Ligas, A;	A medium-term, stochastic forecast model to support sustainable, mixed fisheries management in the Mediterranean Seaa	2013	Journal of Fish Biology
Thorpe, R B; Le Quesne, W J F; Luxford, F; Collie, J S;	Evaluation and management implications of uncertainty in a multispecies size-structured model of population and community responses to fishing	2015	Methods in Ecology and Evolution
Tidd, A N	Effective fishing effort indicators and their application to spatial management of mixed demersal fisheries	2013	Fisheries Management and Ecology
Trenkel, V M; Rochet, M J; Rice, J C	A framework for evaluating management plans comprehensively	2015	Fish and Fisheries
Trondsen, T; Matthiasson, T; Young, J A	Towards a market-oriented management model for straddling fish stocks	2006	Marine Policy
Van Putten, I E; Quillérou, E; Guyader, O	How constrained? Entry into the French Atlantic fishery through second-hand vessel purchase	2012	Ocean and Coastal Management

4 Appendix S4.

Table of all Level 2 variables and their frequency (count).

Level 2	Count
Acceptance Of Management Regime	1
Attitudes On Regulatory Options	1
Central Bank-Like Of Fishery Resources	1
Change In TAC Level	1
Closed Areas	1
Commitment	1
Compliance	2
Components and Interrelationships Of Fishery	1
Conflicts	1
Diagnostics	1
DPSIR Indicators	1
Employment Opportunities	1
Fleet	1
Fleet Adaptation	1
Impact of Shocks to Aquaculture	1
Implementation Uncertainty	1
Interests	1
Intervention	1
ITQs	1
Management Decision	1
Management Measures	4
Management Option	2
Material Wellbeing	1
Motives For Non-Compliance	1
MOVA	1
Normative-Cognitive Configuration	1
Objectives	1
Objectives For Society	1
Participation In Decision-Making Processes	2

Policy Making	1
Preferences	2
Preferred Management Measures	1
Quota Allocation	1
Regulation	1
Relational Wellbeing	1
Social Organizational Configuration	1
Stock Dynamics	1
Subjective Wellbeing	1
Sustainability	1
TAC	1
Tactical Choices	1
Utility	4
Vessel Behavior	1

5 Appendix S5.

Table of all Level 3 variables and their frequency (count).

Level 3	Count
Accessibility	1
Administration Body	1
Aquaculture Escapes	1
Aquaculture Production	1
Area	6
Atmospheric Pressure	1
Authority And Responsibility	1
Believes	2
Biomass	2
Bureaucracy	1
Business Characteristics	2
Capacity	3
Capital	1
Catches	6
Closed Area Or Season	1
Compliance	2
Conceptualization Of Situation	1
Confidence In Management	1
Conservation Systems	1
Consulted	1
Cost	13
CPUE	1
Crew	1
Days At Sea	1
Decision Variables	1
Decision-Making Procedure	1
Decommissioning Grant	1
Demand	3

Demographics	4
Discards	2
Distance	1
Distribution System	1
Earnings	2
Economic Rent	2
Education	1
Effort	13
Employment	3
Existing Wealth	1
Experience	2
Expertise	1
Family Connections	1
Feed	1
Fine	3
Fish Abundance	1
Fishing Gear	1
Fishing Mortality	4
Fishing Operation Characteristics	1
Fishing Points	1
Fleet	2
Fuel	5
GDP	1
Go Out Fishing Or Stay In Port	1
Goals And Priorities	1
Government	1
Government Support	2
Harvest	2
Holistic View	1
Immigration Flows	1
Implementation	1
Income	2
Industry Support	1

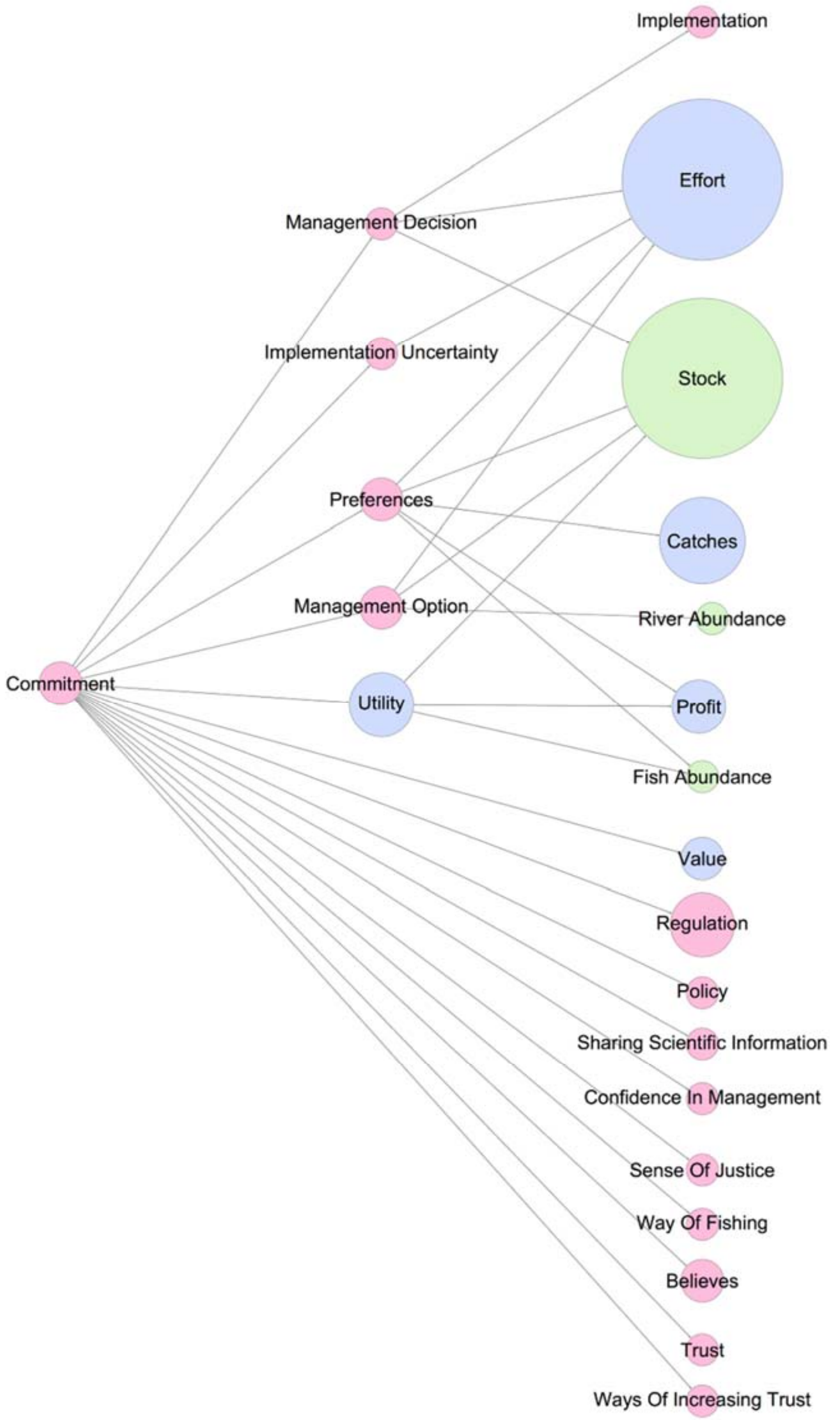
Info From Other Fishers	1
Informed	1
Involved	1
Labour	1
Landings	8
Legitimacy	1
Local Fishing Interests	1
Market Trader Network Structure And Dynamics	1
Material Resources	1
Metier	4
Monetary Return	1
Monitoring Programme	1
Moral Norm	1
Mortality Reduction	1
Multispecies	1
Natural Resources	1
Needs For A Good Life	1
Network Integration	1
Number Of Participants Or Fishers	1
Number Of Vessels	5
Others Are Cheating	1
Performance Indicators	1
Policy	1
Pollution	1
Ports, Harbours	1
Prices	12
Probability Of Being Caught	1
Probability Of Making A Choice	1
Problems	2
Production	1
Profit	3
Profitability	1
Quota	6

Regulation	4
Regulatory Preferences	1
Relationships Influencing Fishing	1
Resource Rent	1
Revenue	7
Risk	1
River Abundance	1
Rules	1
Sense Of Justice	1
Sharing Scientific Information	1
Social Preferences	1
Social Pressure	1
Social Resources	1
Solutions	1
Species	2
Spawning Stock Biomass	1
Stakeholders	1
State Of Nature	1
Stock	13
Strength Of Relationship Between Variables	1
Subsidies	1
Supply	1
TAC	7
TAE	1
Tax	3
Technological Parameters	1
Time	3
Trip	1
Trust	1
Uncertain Variables Of Fishery	1
Utility, Loss, Preference Variables	1
Value	2
Vessel	4

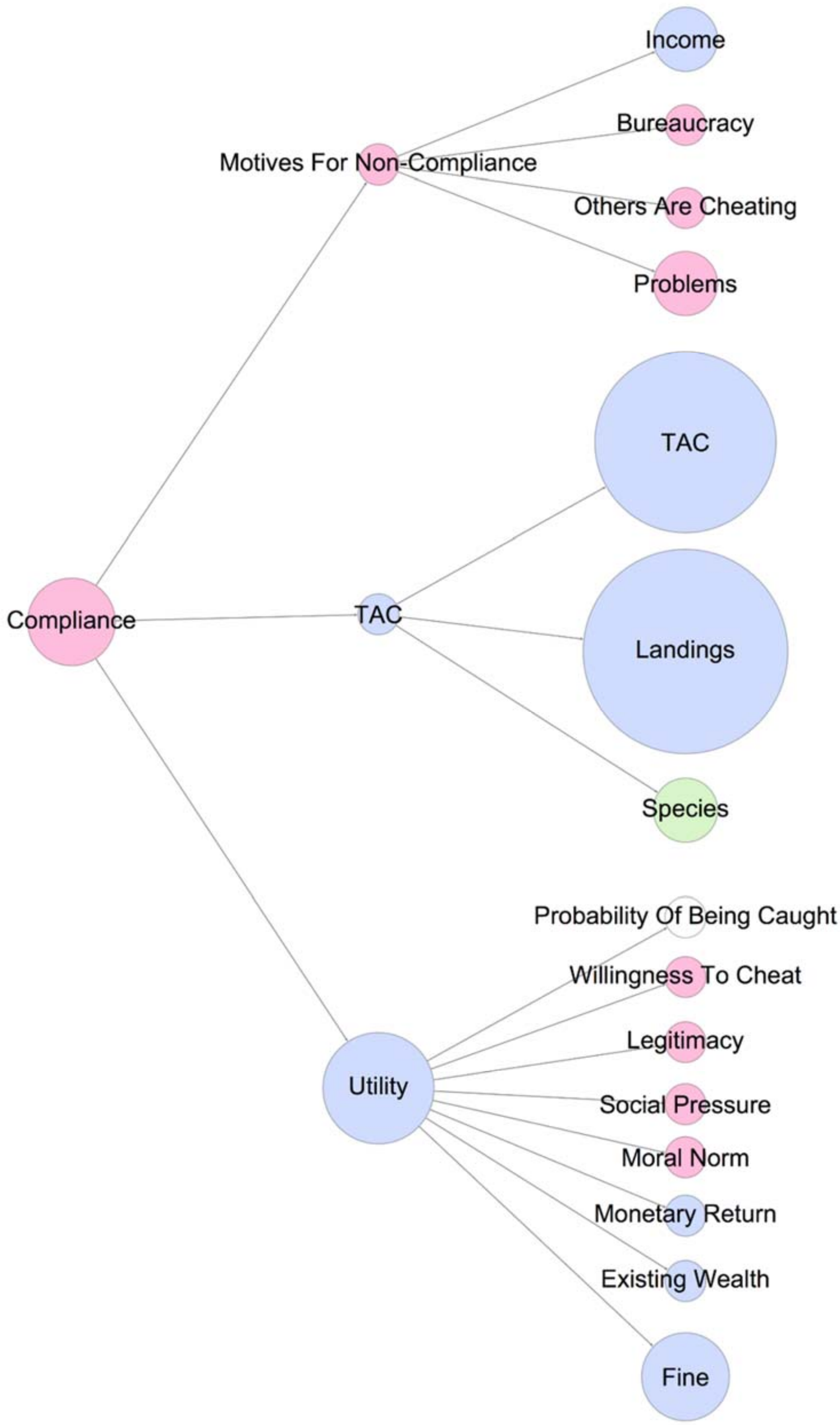
Veto Right	1
VPA	1
VPUE	1
Waste	1
Way Of Fishing	1
Ways Of Increasing Trust	1
Weather	1
Weight	2
Willingness To Cheat	1
Yield	3

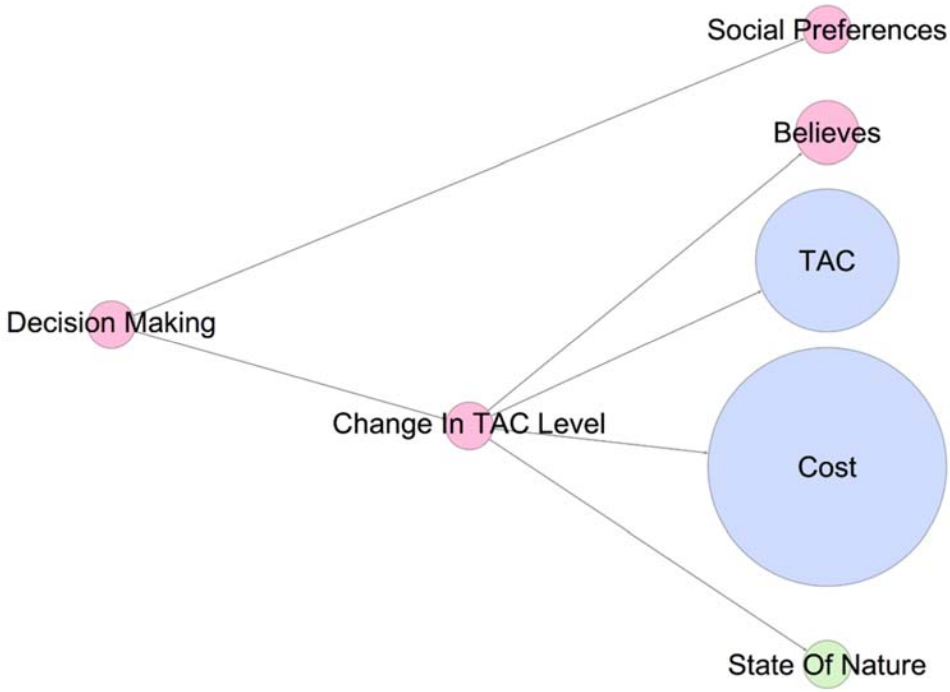
6 Appendix S6.

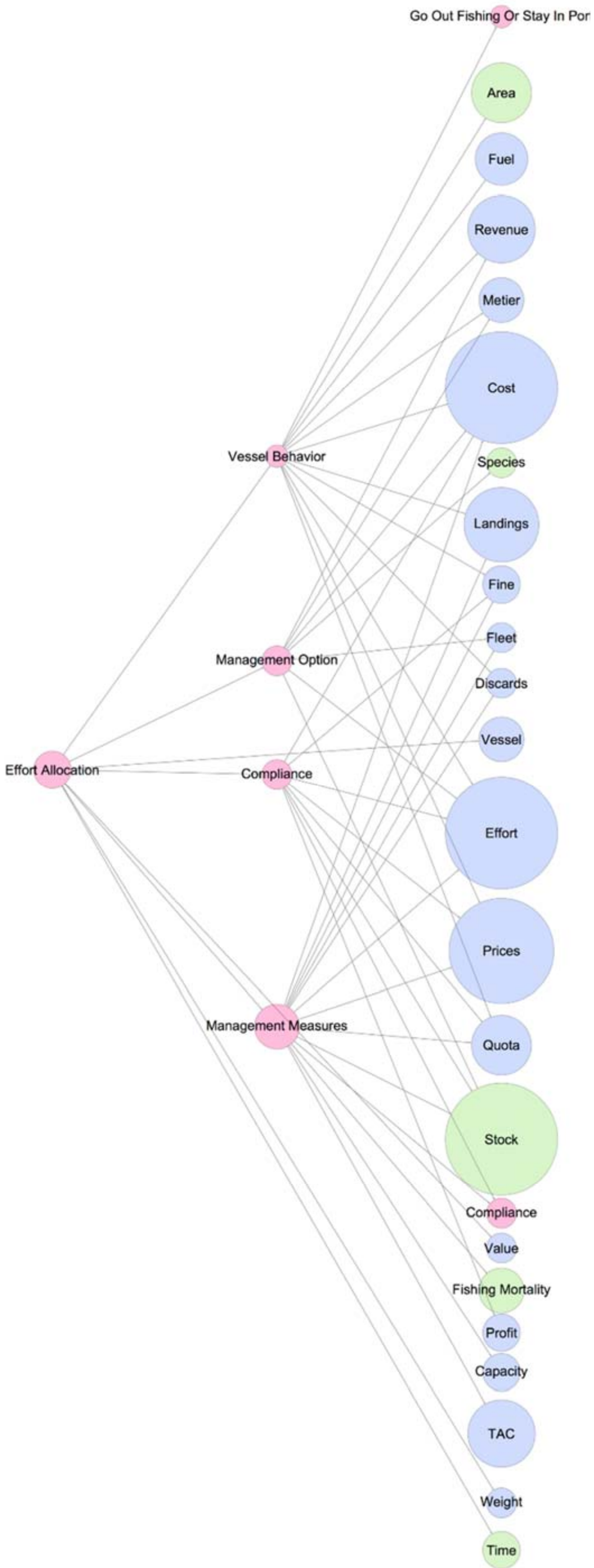
Individual visualizations of all human dimension aspects and their level 2 and level 3 variables. Human dimension aspects are listed in alphabetical order. The color of the node indicates the dimension it belongs to, with pink = human, blue = economic, green = environmental, and white = other / more than one dimension; Size of the node shows relative importance, i.e. the number of publications that used this node; hierarchy of the nodes is displayed by order from left to write, where nodes on the very left are level 1 human dimension aspects, nodes in the middle are level 2 variables, and nodes on the very right are level 3 variables.

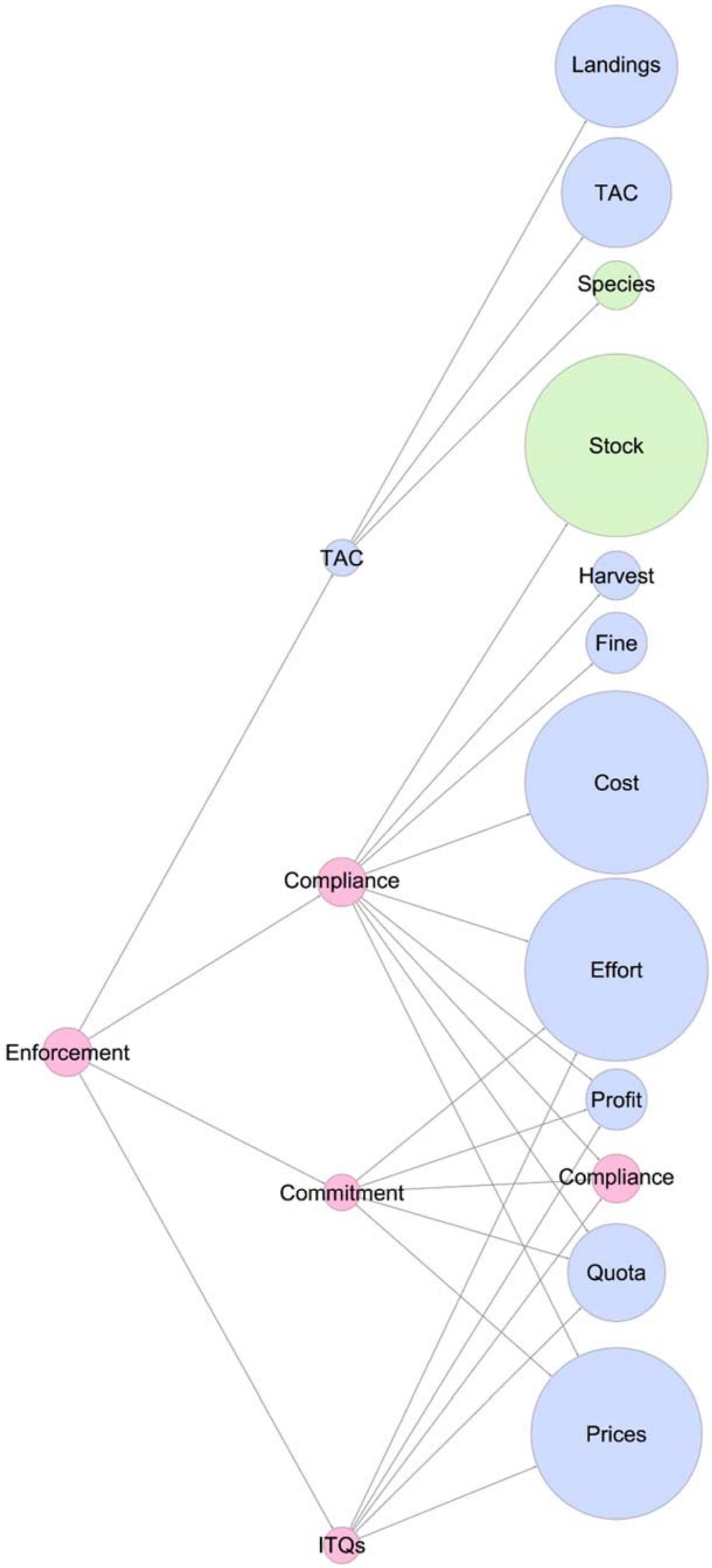


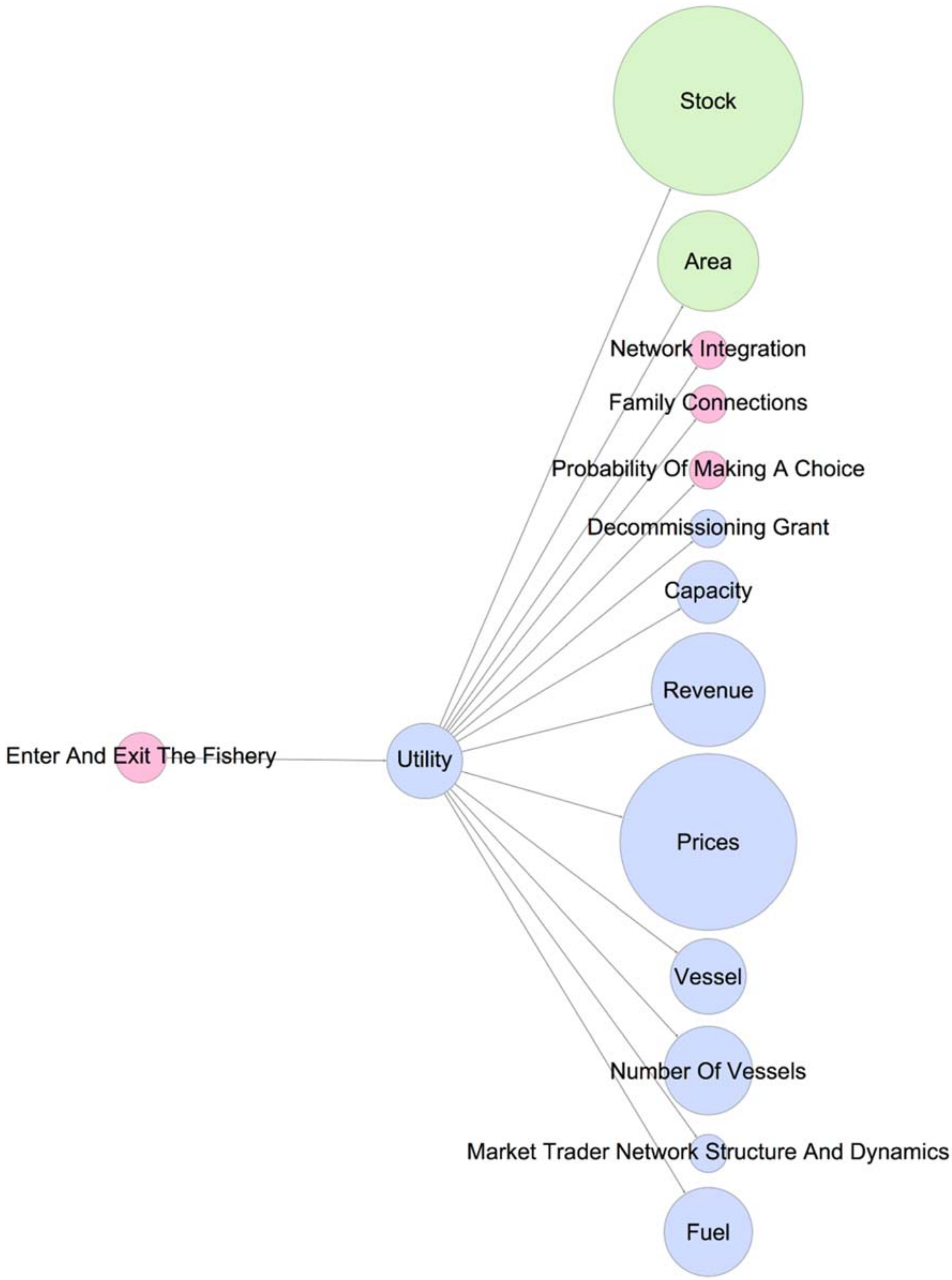
Implementation
Effort
Management Decision
Implementation Uncertainty
Stock
Preferences
Catches
Management Option
River Abundance
Commitment
Utility
Profit
Fish Abundance
Value
Regulation
Policy
Sharing Scientific Information
Confidence In Management
Sense Of Justice
Way Of Fishing
Believes
Trust
Ways Of Increasing Trust

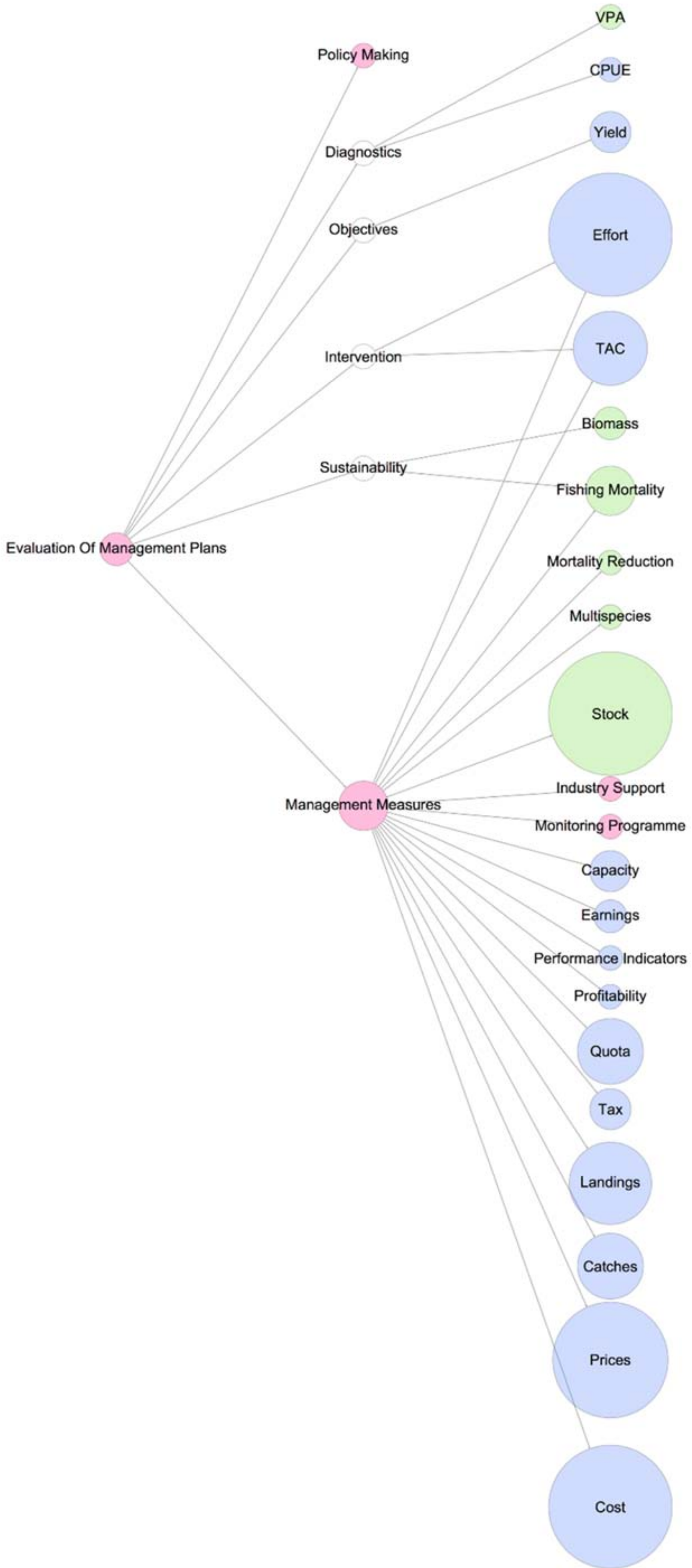

Income
Bureaucracy
Motives For Non-Compliance
Others Are Cheating
Problems
TAC
Compliance
TAC
Landings
Species
Probability Of Being Caught
Willingness To Cheat
Legitimacy
Utility
Social Pressure
Moral Norm
Monetary Return
Existing Wealth
Fine

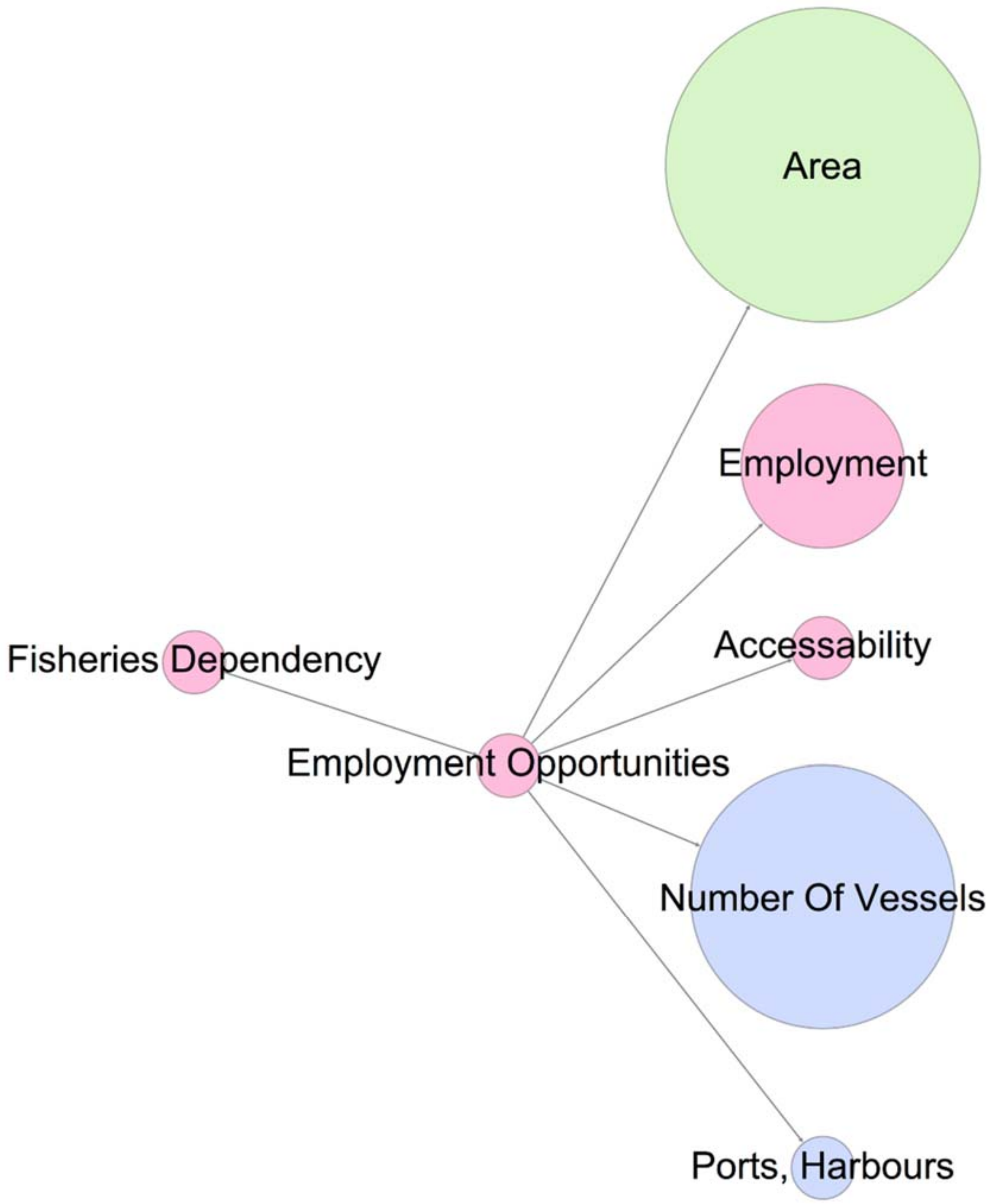

Social Preferences
Believes
TAC
Decision Making
Change In TAC Level
Cost
State Of Nature

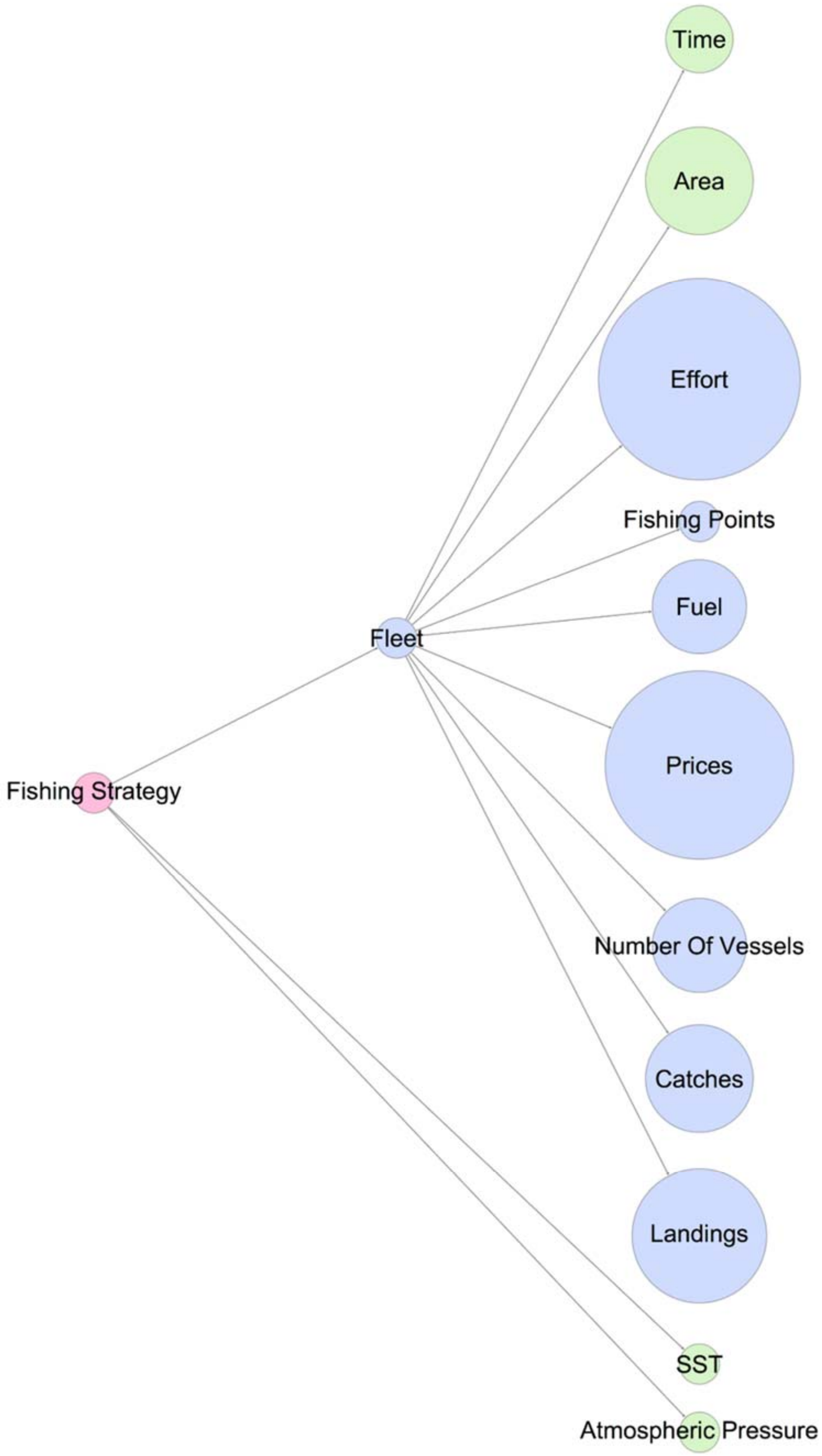

Go Out Fishing Or Stay In Por
Area
Fuel
Revenue
Metier
Cost
Vessel Behavior
Species
Landings
Fine
Fleet
Management Option
Discards
Vessel
Effort Allocation
Compliance
Effort
Prices
Management Measures
Quota
Stock
Compliance
Value
Fishing Mortality
Profit
Capacity
TAC
Weight
Time

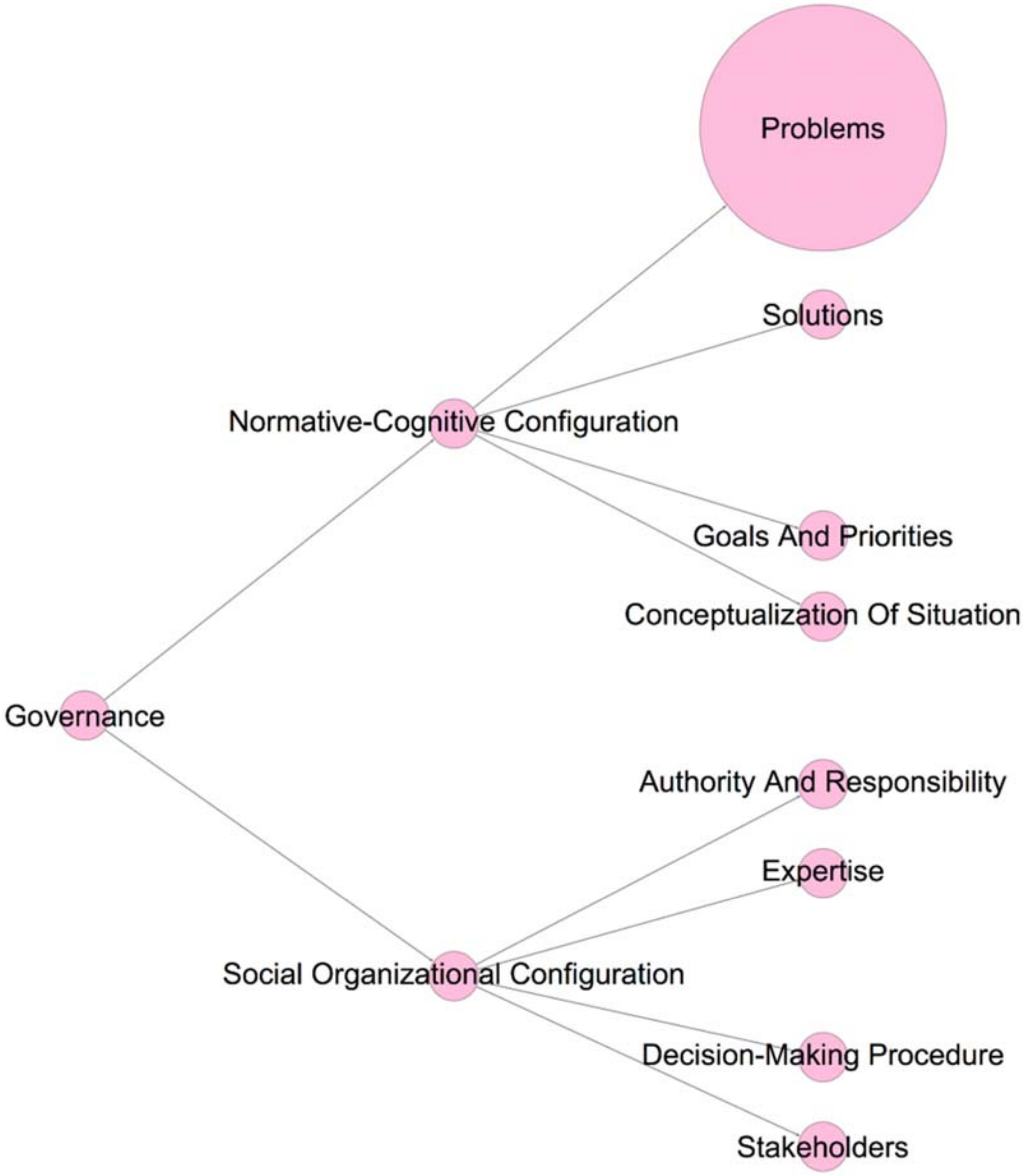

Landings
TAC
Species
Stock
TAC
Harvest
Fine
Cost
Compliance
Effort
Enforcement
Profit
Commitment
Compliance
Quota
Prices
ITQs

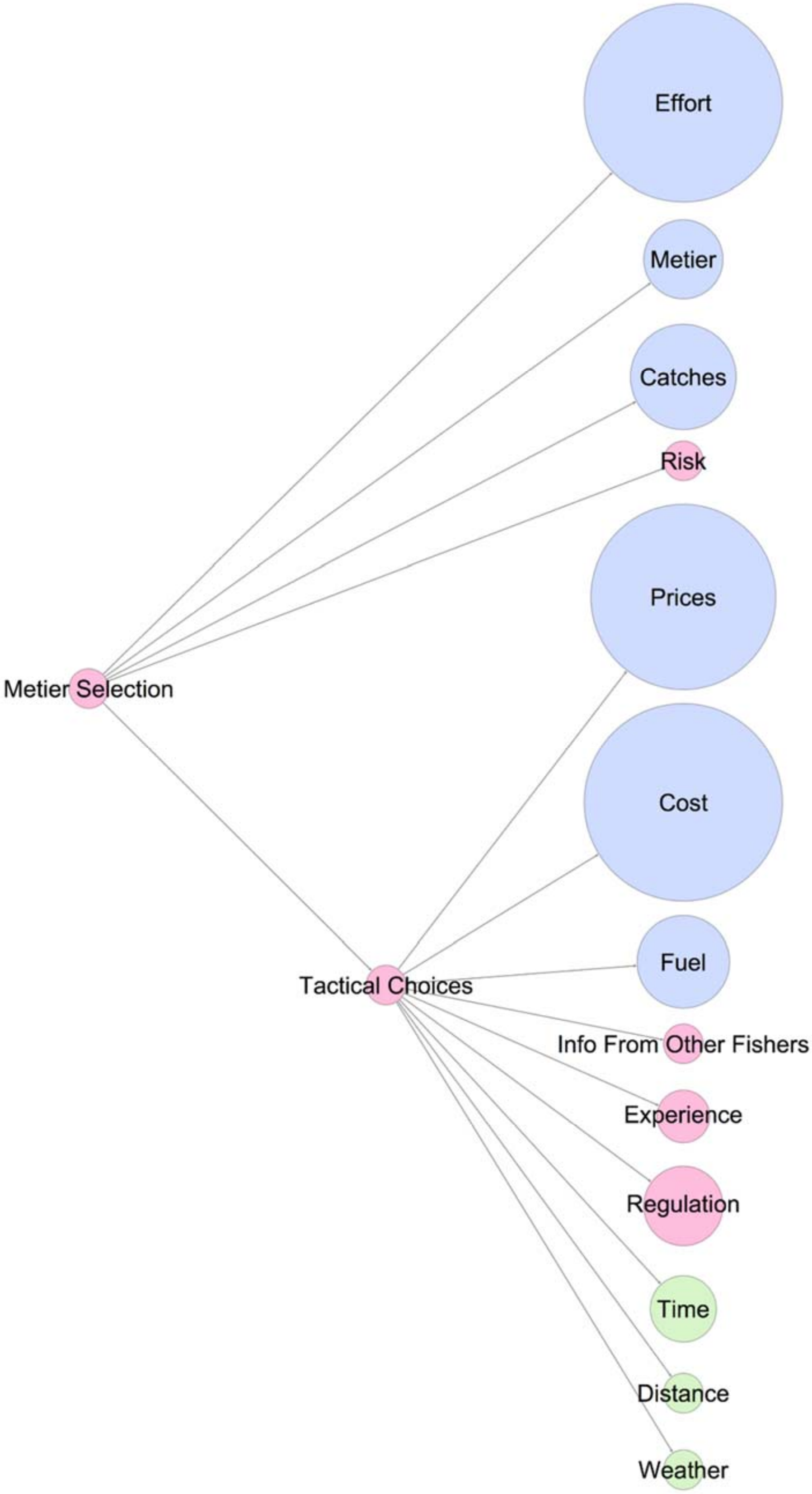

Stock
Area
Network Integration
Family Connections
Probability Of Making A Choice
Decommissioning Grant
Capacity
Revenue
Enter And Exit The Fishery
Utility
Prices
Vessel
Number Of Vessels
Market Trader Network Structure And Dynamics
Fuel

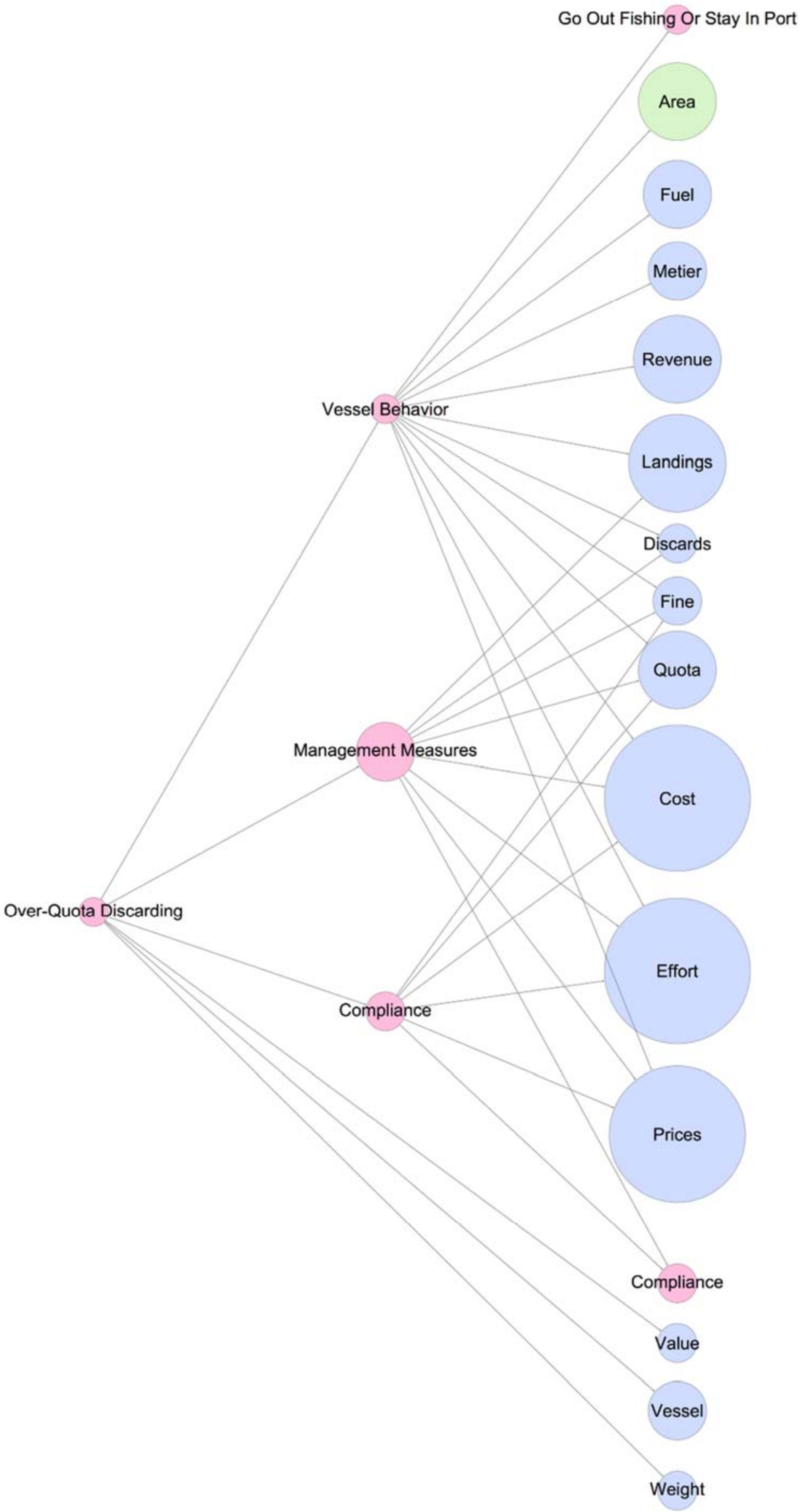

VPA
Policy Making
CPUE
Yield
Diagnostics
Objectives
Effort
Intervention
TAC
Biomass
Sustainability
Fishing Mortality
Evaluation Of Management Plans
Mortality Reduction
Multispecies
Stock
Industry Support
Management Measures
Monitoring Programme
Capacity
Earnings
Performance Indicators
Profitability
Quota
Tax
Landings
Catches
Prices
Cost

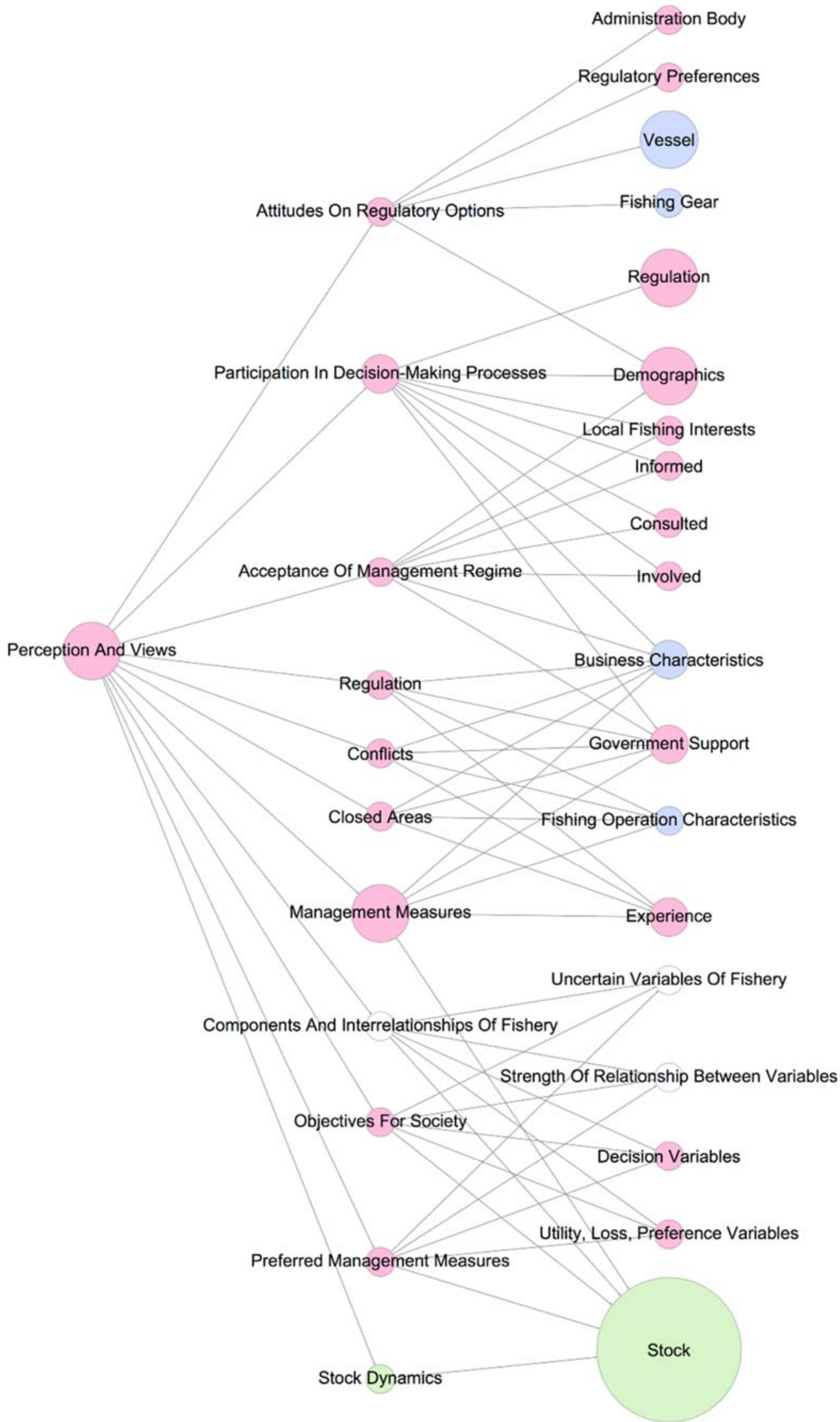

Area
Employment
Accessability
Fisheries Dependency
Employment Opportunities
Number Of Vessels
Ports, Harbours

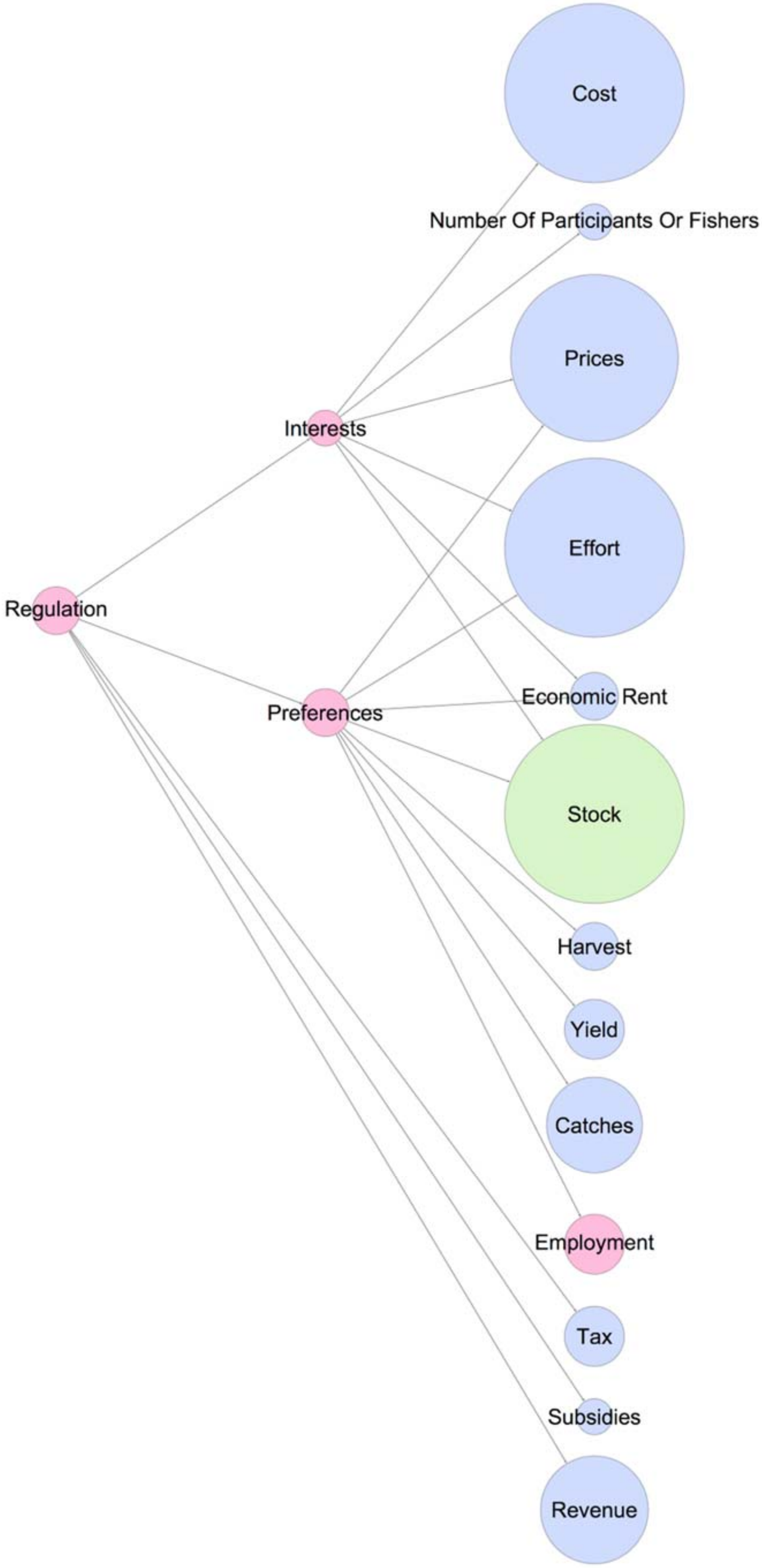

Time
Area
Effort
Fishing Points
Fuel
Fleet
Prices
Fishing Strategy
Number Of Vessels
Catches
Landings
SST
Atmospheric Pressure

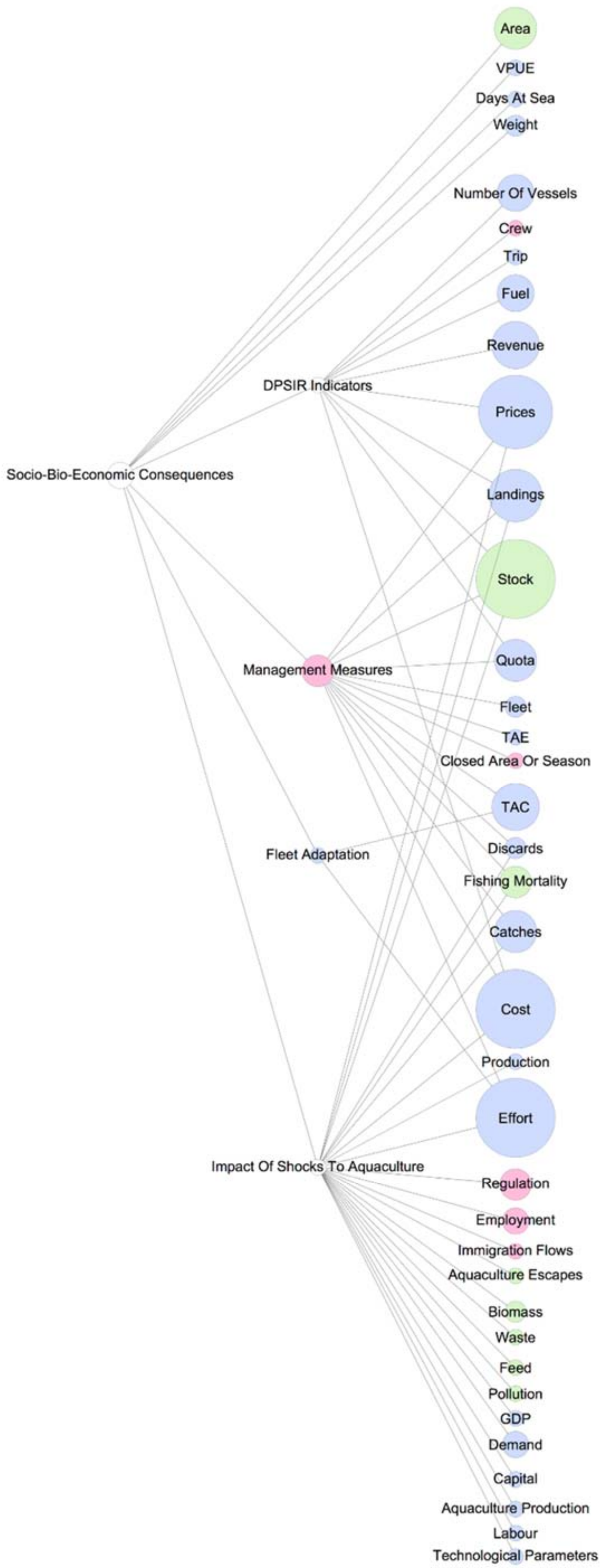

Problems
Solutions
Normative-Cognitive Configuration
Goals And Priorities
Conceptualization Of Situation
Governance
Authority And Responsibility
Expertise
Social Organizational Configuration
Decision-Making Procedure
Stakeholders

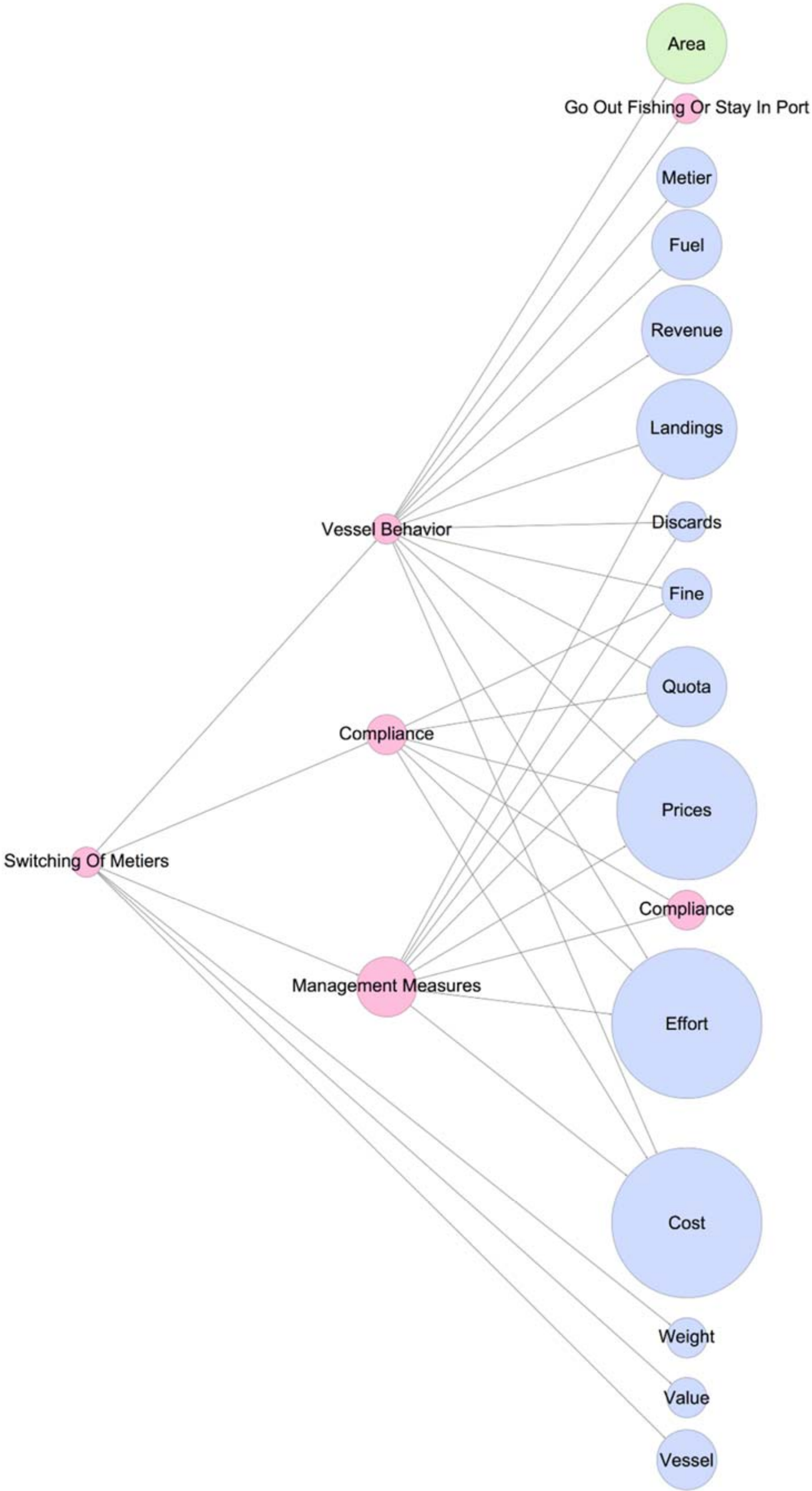

Effort
Metier
Catches
Risk
Prices
Metier Selection
Cost
Fuel
Tactical Choices
Info From Other Fishers
Experience
Regulation
Time
Distance
Weather

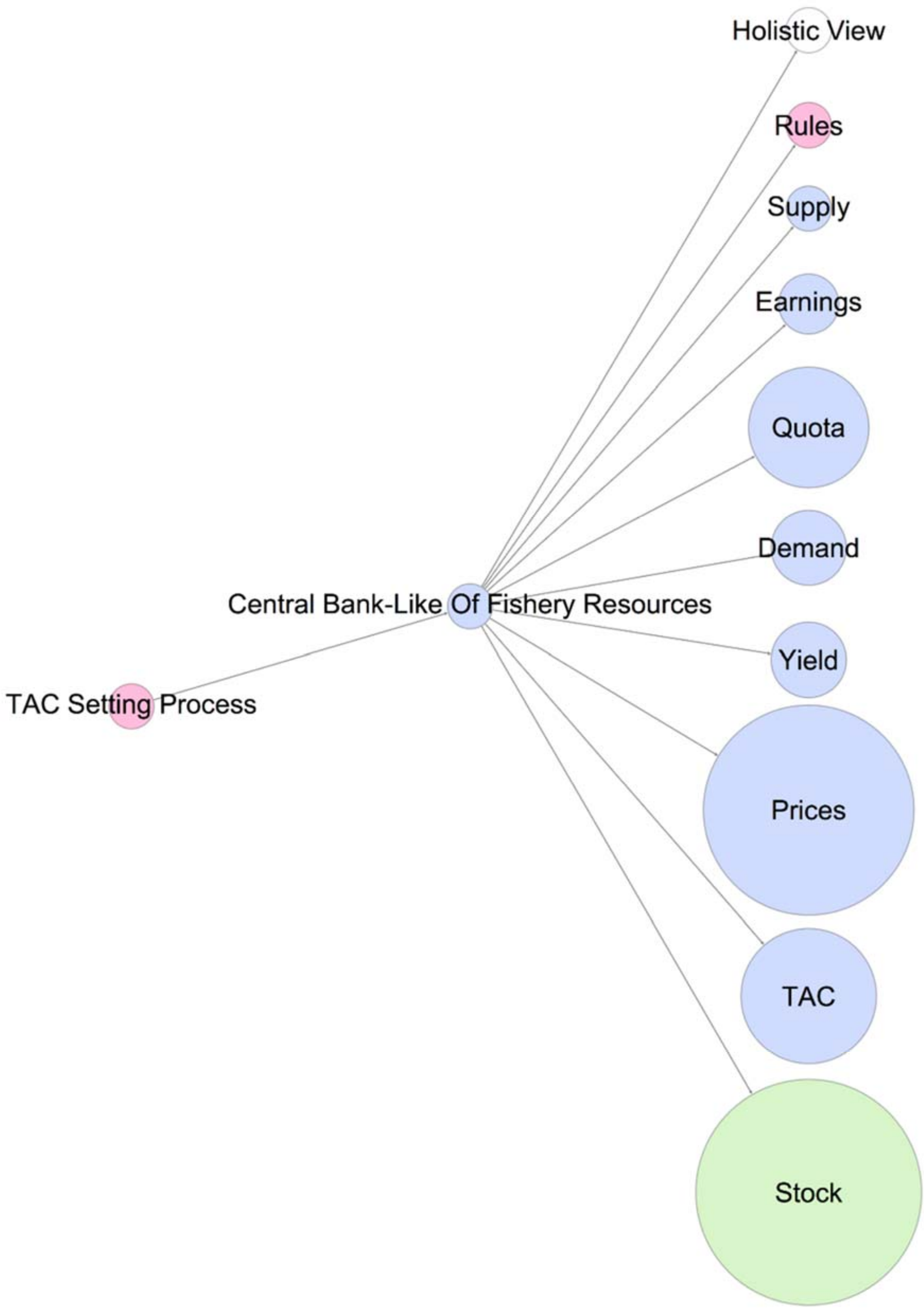

Go Out Fishing Or Stay In Port
Area
Fuel
Metier
Revenue
Vessel Behavior
Landings
Discards
Fine
Quota
Management Measures
Cost
Over-Quota Discarding
Effort
Compliance
Prices
Compliance
Value
Vessel
Weight

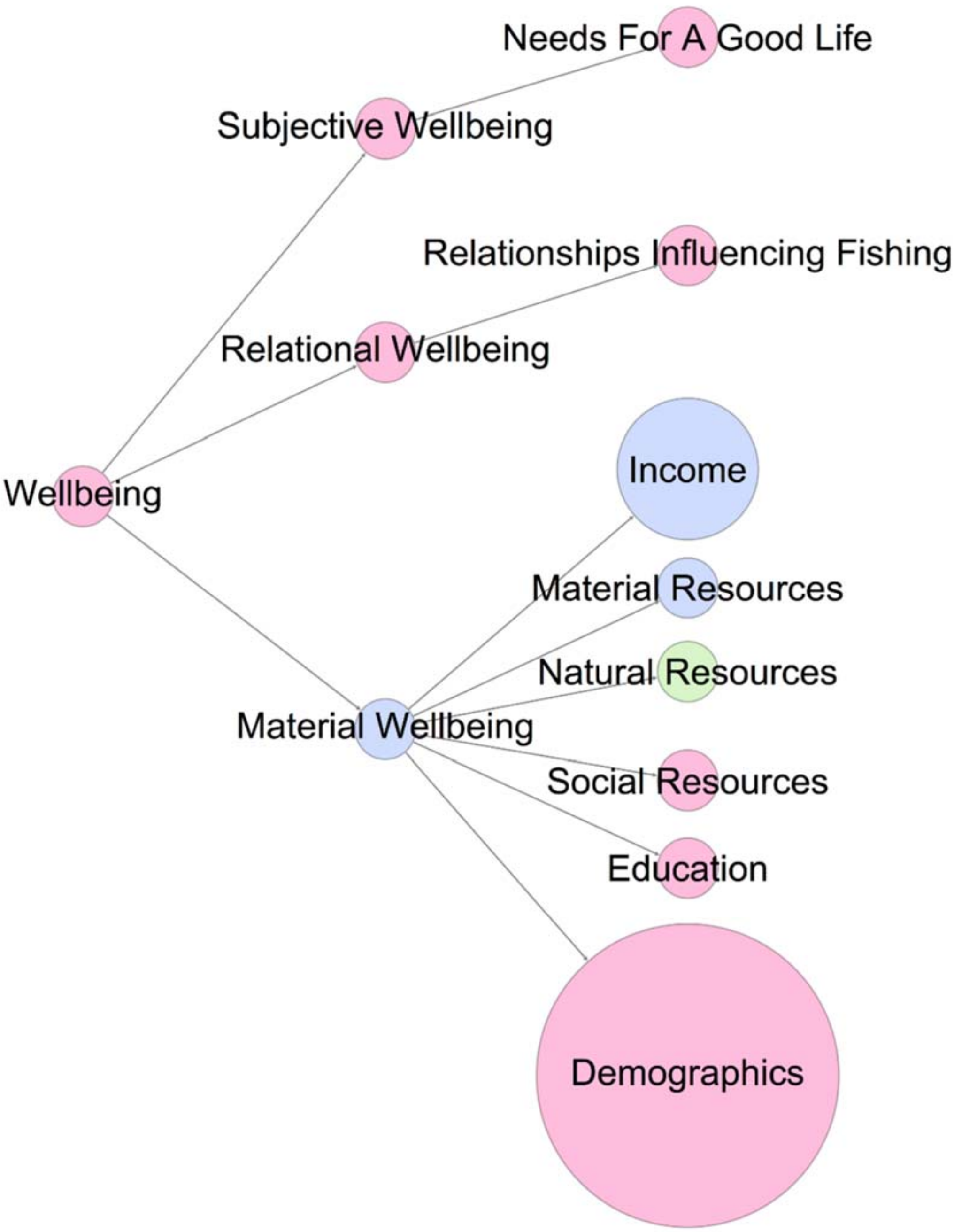

Administration Body
Regulatory Preferences
Vessel
Fishing Gear
Attitudes On Regulatory Options
Regulation
Participation In Decision-Making Processes
Demographics
Local Fishing Interests
Informed
Consulted
Acceptance Of Management Regime
Involved
Perception And Views
Business Characteristics
Regulation
Conflicts
Government Support
Closed Areas
Fishing Operation Characteristics
Management Measures
Experience
Uncertain Variables Of Fishery
Components And Interrelationships Of Fishery
Strength Of Relationship Between Variables
Objectives For Society
Decision Variables
Utility, Loss, Preference Variables
Preferred Management Measures
Stock
Stock Dynamics


Cost
Number Of Participants Or Fishers
Prices
Interests
Effort
Regulation
Economic Rent
Preferences
Stock
Harvest
Yield
Catches
Employment
Tax
Subsidies
Revenue


Area
VPUE
Days At Sea
Weight
Number Of Vessels
Crew
Trip
Fuel
Revenue
DPSIR Indicators
Prices
Socio-Bio-Economic Consequences
Landings
Stock
Management Measures
Quota
Fleet
TAE
Closed Area Or Season
TAC
Fleet Adaptation
Discards
Fishing Mortality
Catches
Cost
Production
Effort
Impact Of Shocks To Aquaculture
Regulation
Employment
Immigration Flows
Aquaculture Escapes
Biomass
Waste
Feed
Pollution
GDP
Demand
Capital
Aquaculture Production
Labour
Technological Parameters


Area
Go Out Fishing Or Stay In Port
Metier
Fuel
Revenue
Landings
Vessel Behavior
Discards
Fine
Quota
Compliance
Prices
Switching Of Metiers
Compliance
Management Measures
Effort
Cost
Weight
Value
Vessel


Holistic View
Rules
Supply
Earnings
Quota
Demand
Central Bank-Like Of Fishery Resources
Yield
TAC Setting Process
Prices
TAC
Stock


Needs For A Good Life
Subjective Wellbeing
Relationships Influencing Fishing
Relational Wellbeing
Wellbeing
Income
Material Resources
Natural Resources
Material Wellbeing
Social Resources
Education
Demographics