Co-production of knowledge beyond health in the SES of the Transition of the Butroe River and Plentzia Bay

One Health Observatory Lighthouse

HOBE Project Technical Report

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Context

The One **H**ealth **Ob**servatory Lighthous**e** – HOBE ("*better*" in the Basque language) project is being carried out in the Bay of Plentzia, the Butroe River that flows into it, and all its watershed. It is implemented by the Plentzia Marine Station (PiE, by its acronym in the Basque language) and by the Basque Centre for Climate Change (BC3). The HOBE project aims to understand how climate change modifies the impacts of coastal pathogens on human, animal, and ecosystem health using a One Health perspective.

The objectives of subproject 2 of the HOBE project (lead by BC3) aim: (i) to develop a conceptual framework which could assist the analysis of the case study area from a watershed perspective, to understand the interconnections among multiple factors and pressures, such as environmental contamination, climate change and socio-economic activities in the coastal-marine landscape, and (ii) to support the construction of a pilot One Health Living Lab, aiming at encouraging collaboration among local agents in the case study area, and supporting a living knowledge platform for multidimensional analysis, collaboration, and research to provide increased evidence of pollution, climate change, and other impacts from the One Health approach and the watershed perspectives.

The first part of the project aimed to focus on literature reviews and internal HOBE workshops to define an integrated health perspective for approaching the health status of the Bay of Plentzia. We elaborated a Conceptual Framework for an extended One Health based on the literature review on human, animal, and ecosystem health, and we tested it with the HOBE team members (Deliverable 2.1. Chapter 1). We obtained an influence diagram where cause-effect relations are depicted between components that define human health, animal health, socio-economic determinants of health, and nature's contributions to all living beings. This network of interactions ultimately represents how health is articulated within a Socio-Ecological System (SES).

SESs are complex, dynamic, adaptative and inherently uncertain (IPBES, 2024; Gray et al., 2015), with context-specific characteristics unique to each system. Consequently, while a general One Health Conceptual Framework provides a structured approach to understanding the SES of the Bay of Plentzia, it may not fully capture the area's local nuances. To address this, a more detailed review, focusing primarily on grey literature, was undertaken to adapt and implement the Conceptual Framework to the specific context of the Bay of Plentzia SES (Deliverable 2.1. Chapter 3). The analysis identified numerous health determinants outlined in the Conceptual Framework as present in the area. These determinants interact within a complex network, where individual factors influence one another and collectively affect various health domains.

Nevertheless, published research, alongside available information and accessible databases, offers only a partial understanding of the system. At the same time, many other characteristics remain only visible to those who live within it. While comprehensively understanding all components and interactions that define the health status of the Bay of Plentzia is challenging, the knowledge of those who experience it can provide valuable insights. Therefore, our work required further enhancement through knowledge co-production methodologies to identify the key cause-effect interactions and factors shaping health in the Bay of Plentzia. These approaches integrated the insights of local residents and experts, enabling us to effectively address the primary health-related issues across the three domains—human, animal, and ecosystem health—in the Bay of Plentzia. This document presents the process of knowledge co-production in our study area.

Introduction

Knowing how social and ecological processes work is essential to address emerging global crises. Donna Haraway's "situated knowledge" concept offers an alternative approach to knowledge generation by challenging traditional science perspectives and their role in explaining social and ecological processes (Haraway, 1988). Haraway critiques the idea of a singular, all-knowing standpoint and emphasises the value of partial, embodied, and situated perspectives that acknowledge their own limitations and context. All knowledge comes, therefore, from specific perspectives and is shaped by the experiences, context, and interests of those who produce it. Subjects, agents, areas of knowledge, and narratives are fundamentally diverse and cannot be reduced to a single viewpoint (Haraway, 1988). "Situated knowledge" can help us better understand the multiple and diverse components that conform to our intricate socio-ecological systems (SESs). To address the socio-ecological crisis and reveal new, richer, and more inclusive understandings of the world, research and knowledge production should include communities and pluralities of perspectives, not only isolated individuals (Schipper et al., 2021).

Emerging challenges in SESs (e.g., climate change, biodiversity loss, global pandemics…) are influenced by various drivers operating across multiple scales, and tackling them effectively requires the integration of multiple knowledge (Norström et al., 2020; Pfenning-Butterworth et al., 2024; Rycroft-Malone et al., 2016). Several challenges have historically hindered progress in inter- and transdisciplinary research, including the lack of funding support, different research methods, epistemological disagreements and the practical challenges of working with complex systems, such as discrepancies in scale, non-linear trends, and siloed research cultures (Pfenning-Butterworth et al., 2024; Schipper et al., 2021). However, today, there is an increasing scientific and political consensus on the need for research integrating multiple fields to tackle socio-ecological challenges (Elixhauser et al., 2024; Pfenning-Butterworth et al., 2024; Schipper et al., 2021).

In health research, the growing recognition of the interconnectedness between humans, non-humans, and the environment highlights our shared dependence on one another (Buse et al., 2018; Lerner & Berg, 2017; Rabinowitz et al., 2018). However, the historically shaped structure of societies and disciplines, along with the sector-specific distribution of resources in healthcare, has hindered the development of integrated approaches (Rüegg et al., 2017). Current public health challenges include multiple disciplines, sectors and professions that work with various data types (from patient histories and clinical tests to medical images and demographic characteristics), all subject to ambiguity and uncertainty (Green, 2006; Groumpos, 2021; Sell et al., 2022). Collaboration has remained scarce, and efforts to understand diseases and create tools to combat them are often disconnected from the initiatives to deliver interventions (Keusch et al., 2010). Many desired health outcomes are not possible to obtain through sectoral approaches alone because of their complexity and intersecting nature, which evidences the need for collaboration between disciplines that not only address human health but also integrate areas of health for non-humans and the environment (Choi & Pak, 2006; Rüegg et al., 2017; Sell et al., 2022; Zinsstag et al. 2023). The integrated One Health approach addresses these issues, including the social and environmental factors characteristic of the SES (Zinsstag et al., 2023). Among its fundamental principles, One Health includes equity between sectors and disciplines, transdisciplinary and multisectoral collaboration, socio-political and multicultural parity, and inclusivity of modern and traditional forms of knowledge (One Health High-Level Expert Panel (OHHLEP) et al., 2022). In this context, One Health promotes adaptative health management

across human, animal, and ecosystem interfaces through transdisciplinary collaboration (Hitziger et al., 2021; Zinsstag et al., 2023).

In transdisciplinary approaches, partnerships between academic and non-academic, local and regional experts and stakeholders have become essential, rather than solely relying on traditional scientific methods (Keusch et al., 2010; Norström et al., 2020). Human communities interact with ecosystems in diverse ways, shaping distinct perceptual and behavioural feedbacks within SESs. Adopting an open, deliberative, and reflexive attitude when addressing One Health in SESs is crucial to include broad perspectives that incorporate differences in knowledge, values, and beliefs of stakeholder groups involved (Norström et al., 2020; Schipper et al., 2021; Schwermer et al., 2021). Knowledge co-production has emerged as a new strategy to unite researchers and societal actors, promote the integration of this multiplicity of knowledge to investigate complex socio-ecological challenges and drive action and societal change (Chambers et al., 2021; Norström et al., 2020). In the healthcare system, patients, caregivers, practitioners, researchers, and policymakers come together around health issues, each bringing a distinct cognitive and emotional perspective shaped by their unique experiences and interests (Rycroft-Malone et al., 2016). Co-production with local stakeholders enables, in this way, the integration of a plurality of perspectives to develop context-driven, problem-focused strategies that generate situated knowledge within its real-world context of application, bridging the gap between those who produce knowledge and those who apply it (Rycroft-Malone et al., 2016). The principles of knowledge co-production emphasise the need to situate research within a particular context, recognise multiple ways of knowing, define shared goals, and promote active engagement among stakeholders (Norström et al., 2020). This approach aligns with the broader aims of One Health (OHHLEP et al., 2022). Therefore, transdisciplinary and co-production offer a pathway for more impactful and urgent outcomes in healthcare (Keusch et al., 2010; Rycroft-Malone et al., 2016).

Various factors and causal forces within diverse populations and multi-layered ecological and societal contexts shape health outcomes in complex, dynamic SESs. Integrating perspectives from various experts and stakeholders has already proven essential, but complex systems cannot be fully understood by focusing solely on their isolated components. It also requires examining the connections between these parts and addressing the emergent behaviour arising from their interaction (Pfenning-Butterworth et al., 2024). Systems thinking is a helpful tool for understanding the intricate environmental processes and societal conditions that impact the health domain (Green, 2006; Hitziger et al., 2021; Leischow et al., 2008; Zinsstag et al. 2011). As suggested by Zinsstag et al. (2011), here we approach "health in socio-ecological systems" (HSES) with a comprehensive, systemic perspective on the interconnected health of humans, animals, and the ecosystem in which they co-exist. A way to address the complexity of these interconnections is through the subjective knowledge of individuals familiar with the system, fostering awareness of internal assumptions regarding how the system operates (Gray et al., 2015).

Cognitive maps are external representations of internal mental models that reflect the foundation of an individual's organised understanding of the world around them (Gray et al., 2015). Cognitive maps can be effectively employed to understand changes and transitions within SESs by facilitating knowledge sharing to define the system's state space and examining its structural components (Gray et al., 2015). The Fuzzy Cognitive Maps (FCM) methodology, built upon earlier work on cognitive maps by Axelrod (1976), was proposed by Kosko (1986). FCMs incorporate fuzzy logic into cognitive maps, representing causal relationships with varying degrees of certainty (Gray et al., 2014; Özesmi & Özesmi, 2004; Schwermer et al., 2021). They are

essentially semi-quantitative graphical representations of individual or collective mental models of a system where relationships between key components are visually illustrated with their weights and directions (Gray et al., 2015). A FCM is built of components, also known as "nodes", "factors", or "concepts", and the connections or "edges" that link them with a causal relationship. Components are variables that can increase or decrease in quality or quantity, and connections are arrows between components representing causal relationships. Each connection has an associated weight that ranges from {-1, 0} to {0, 1}, where the sign indicates the direction of the relationship (direct or inverse) and the metric, its intensity (0 indicates "no influence" and 1 "strong influence"). The network of connections can be represented as an adjacency matrix, which allows for an algebraic representation of the system and, therefore, standard mathematical operations to analyse the relationships between nodes. Network analysis of the obtained FCMs becomes a valuable tool for mapping SES complexity and uncovering connections among its parts (Castro et al., 2023).

In recent years, FCMs have been used as a participatory methodology for knowledge co-production in studies addressing water management (Castro et al., 2023; Tepes & Neumann, 2020), health promotion (Sarmiento et al., 2024; Saúl et al., 2022), climate change adaptation (Olazabal, Chiabai, et al., 2018), and socio-ecological systems (Gray et al., 2015; Schwermer et al., 2021), among others. FCMs are particularly useful in fields marked by complexity, ambiguity, subjectivity, and limited data (Gray et al., 2014; Nair et al., 2019). Using FCMs enables the capture of participants' knowledge, experiences, and beliefs regarding the workings of a specific system, thereby making implicit assumptions or uncertain mental models more explicit. Empirical data is, therefore, not essential, and knowledge is built from the local experience of people who have co-evolved with the system in question (Özesmi & Özesmi, 2004). Additionally, FCMs can help evaluate how modifications in structural configurations might influence shifts toward more favourable or unfavourable future outcomes. Rather than serving solely as a formal assessment tool, FCMs are valuable in fostering social learning and encouraging dialogue among diverse stakeholders (Barbrook-Johnson & Penn, 2022; Gray et al., 2015). By fostering collaborative and iterative knowledge production, this approach enables a comprehensive understanding of health challenges and encourages joint action, ultimately contributing to more effective governance and decision-making (Castro et al., 2023). These characteristics facilitate the interpretation of systems that otherwise would remain very complex. On the other hand, FCMs also have limitations related to fully capturing the semantics of causality, time relations, and the fuzziness of concepts (Carvalho, 2013; Nair et al., 2019), which leads to potential misinterpretation of dynamic FCM outputs.

In inter- and transdisciplinary health research within SESs, knowledge co-production and systems thinking are valuable strategies for strengthening One Health initiatives (Hitziger et al., 2021; Pfenning-Butterworth et al., 2024; Zinsstag et al., 2023). This study aims to explore expert perceptions to generate scientific insights into the health challenges facing the Bay of Plentzia. To achieve this, we organised cognitive mapping sessions and developed 17 FCMs, integrating perspectives from local stakeholders familiar with the area. Our goal was not only to incorporate stakeholders' beliefs to understand their perception of the system's structure but also to capture their social values and preferences, enabling the identification of management goals and key attributes valued within the system (Gray et al., 2015). We analysed the network structure embedded within each FCM and its unique nuances to pinpoint the primary factors influencing the Bay's health status. By capturing the subjective knowledge of individuals and increasing awareness of underlying system assumptions, this research seeks to illuminate the connections

between various health components, offering an integrated approach to managing the HSES of the Bay of Plentzia.

Methodology

2.1 Interview objective and structure

An individual semi-structured interview was prepared to conduct the FCM. It was designed to last 60 to 90 minutes, during which the participant and the interviewer discussed building the cognitive map together. An interview guideline was developed to standardize the conditions for each interview (see Annex 3), ensuring a consistent approach to gathering participants' perceptions of the factors influencing health in the Bay of Plentzia. For designing individual FCM exercises, two model collection techniques are available: Participants can either use standardized components to construct their maps or start with a blank sheet, allowing them the freedom to define and include concepts. Both approaches are valid, each offering distinct advantages and limitations (Gray et al., 2014). While not providing a predefined list of components introduces greater researcher subjectivity in interpreting concepts and requires more effort to standardize the models for comparability, we chose to allow participants to select their own components. This approach ensured that participants could use their own terminology, feel more at ease during the interview, and avoid being constrained by the researcher's preconceptions of the system (Gray et al., 2014).

We conducted three pilot interviews before initiating the interview process to test the guidelines. These pilots assessed how participants responded to the formulated questions and the FCM methodology, identified potential weaknesses, and refined our approach. Participants for the pilot interviews were selected based on their familiarity with the project and knowledge of the Bay of Plentzia. Annex 1 provides a detailed account of the pilot interviews, lessons learned, and feedback from the interviewees. Using this information, the interview guidelines were revised and finalized for use with experts and stakeholders in the Bay of Plentzia (Annex 3).

The final interview guidelines were structured into two main parts. The first part began with participants signing the required data protection forms, followed by a presentation of the project. This presentation included an overview of the project's scope and objectives. To contextualize the participant's input, a brief questionnaire was provided to gather personal information, such as age range and time spent in the Bay of Plentzia. The interviewer then explained the interview's purpose and the chosen methodology, the FCM. To help participants understand the methodology, an example of an unrelated FCM was shared, and the interviewer carefully outlined the steps involved in the process.

The second part of the interview focused on developing the FCM. Participants were first invited to introduce themselves, explain their area of expertise, and describe their connection to the Bay of Plentzia. The interviewer posed three open-ended questions to guide the discussion during the FCM exercise (Table 1. The three open-ended questions were asked during the interview.Table 1). For Question 1, participants were given three options and encouraged to address any or all of them, depending on their comfort level. The concept of One Health was intentionally omitted to simplify the discussion, as the FCM methodology itself places a cognitive load on participants. This approach allowed participants to freely discuss all health domains or focus on the areas they knew best, making the interview more fluid and less overwhelming. Ecosystem health was conceptualized as "environment health" to avoid the word "ecosystem"

and ensure all participants could understand it. Additionally, each health domain was clarified during the interview if the participant required so.

Question 1 was designed to gather the participant's perspective on the main factors affecting the health of the Bay of Plentzia based on their expertise and experience. Question 2 then encouraged the participant to elaborate on how these factors influence the HSES, particularly if they had only listed them initially. Finally, Question 3 invited participants to propose actions they believed could improve the Bay's HSES. These three carefully formulated questions aimed to elicit insights into the causal interactions between concepts that define the system's dynamics and shape the health of the Bay of Plentzia.

Table 1. The three open-ended questions were asked during the interview.

Question 1	Based on your experience and expertise in the Bay of Plentzia, which elements affect... • ... human health? • ... animal health? • ... environment health?
Question 2	Based on your experience and expertise in the Bay of Plentzia, how do these elements affect the health in the Bay of Plentzia?
Question 3	What actions could be implemented to improve the situation?

2.2 Selection of participants

The objective of our study is to gather the perceptions of experts and stakeholders in the area to co-produce a conceptualisation of the HSES of the Bay of Plentzia and the factors altering it. For this reason, we looked for participants connected to the Bay, either because it is their workplace or because they live there. We ensured that all participants had expertise at least in one of the three health domains: human, animal, or environment.

To identify the possible participants, we conducted a first search on the town council web pages of Plentzia[1], Gorliz[2], and Barrika[3] We elaborated a provisional database with citizens of the three municipalities who worked in fields related to human physical and psychological health, veterinarian medicine, biological sciences, and environmental restoration and conservation. Our initial database was contrasted with HOBE researchers from the PiE-EHU/UPV and completed and modified with new stakeholders to obtain a list of 21 participants. The database included academic experts, local associations and enterprises, private and public health centres, and government structures.

The 21 participants were contacted and invited to participate in the interviews. However, not all of them were available. On the other hand, new stakeholders were added to the database after participants suggested them during their interviews. Finally, 17 stakeholders participated in the interviews.

Table 2. Stakeholders participating in the interviews.

PARTICIPANT	AREA OF EXPERTISE	TYPE OF AGENT
1	Tourism	Local Authority
2	Human physical health	Health
3	Freshwater ecology	Research

[1] https://www.plentzia.eus/es-ES/Paginas/default.aspx
[2] https://www.gorliz.eus/es-ES/Paginas/default.aspx
[3] https://www.barrika.eu/es-ES/Paginas/default.aspx

PARTICIPANT	AREA OF EXPERTISE	TYPE OF AGENT
4	Micobiological ecology	Research
5	Human health	Local Association
6	Recyling of plastics	Research, Local Authority
7	Water sanitation	Enterpise
8	Third sector	Local Association
9	Marine and coastal environment management	Research
10	Biochemistry	Research
11	Medical microbiology	Research
12	Veterinary	Veterinary Medicine
13	Microbiology	Research
14	Economist	Research
15	Human health	Health
16	Human mental health	Health
17	Marine Biology	Local Association

Table 2 shows the list of participating stakeholders. Some clearly focus on one of the three health domains. In contrast, others' expertise is distributed in more than one discipline and, therefore, can act as a nexus between human, animal, and environment health. Participants' expertise includes biological and ecological sciences, human health and social sciences, third sector areas, and veterinarian medicine. Most of them belong to the research environment (eight participants), some to healthcare centres (three participants) and local associations (three participants), others to local authority structures (two participants), and only one to an enterprise and veterinarian medicine (note that Participant 6 belongs both to research and local authority). As can be seen in Table 2, there is only one representative of the veterinarian medicine. Identifying animal health professionals in the area for participation in the interviews proved challenging due to the limited presence of veterinary clinics and the lack of prominence of livestock-related activities. While the Wildlife Recovery Centre and the Farm of the Provincial Council of Bizkaia in Gorliz could have provided valuable insights, we were unable to include them in the study. Participant 12 was the only individual with a veterinary background, though their expertise extended to public health. As reflected in their FCM (see results), their focus leaned more toward the intersection of disciplines rather than specific animal health issues. Consequently, our study lacks the specialized expertise and knowledge of dedicated animal health professionals.

Annexe 2 includes an analysis of the questionnaire given to each participant at the beginning of the interview. Most are over 45 years old (65%) and live in the Bay of Plentzia and its surroundings (59%). Additionally, the majority (65%) consider spending more than 25% of their everyday life in Bay of Plentzia. Only two participants stated that they are not in the area daily and pointed out that they visit it occasionally (Participant 9) and often (Participant 14).

2.3 Conducting the mapping session

Interviews took place in various locations (e.g., meeting rooms, cafés, offices…) based on the participants' preferences. Before starting each interview, participants were informed that the audio would be recorded for later analysis, as outlined in the Data Protection form.

An A3-sized white sheet was provided with sticky notes and coloured markers, inviting participants to write down their responses and build the map. However, nearly all participants preferred verbalising their thoughts, allowing the interviewer to organise the ideas on paper.

This approach ensured that participants could maintain their train of thought while the interviewer captured the main ideas. Before adding them to the map, the interviewer confirmed with the participant whether the concept on the sticky note accurately reflected their intended meaning or if they preferred a different word or phrasing. Once several concepts were on paper, participants were asked to establish causal relationships between them and begin constructing the network that would be the FCM. As the discussion continued, more concepts were added to the map.

Question 2 was designed to expand on Question 1, but in most interviews, it felt redundant as participants had already addressed it within their initial responses. Question 3 was answered using sticky notes in a different colour or circling them with a marker if they had already been mentioned to distinguish the actions suggested by the participants.

After completing the network and asking the participants if they felt satisfied, they were asked to weigh the connections. Connections could be positive (where an increase in one component leads to an increase in another) or negative (where an increase in one component causes a decrease in another). The connections could be rated as strong (±1) or weak (±0.5), indicated by two (++/--) or one (+/-) signs, respectively. Although the limitation to only two possible weights reduced the resolution of the FCM, it also lessened the cognitive load on participants, who were often already mentally fatigued after the process of building the network.

Finally, before concluding the FCM, the interviewer asked if the participants were satisfied with it or wished to make any final adjustments. After each interview, the researcher briefly wrote down comments about the development of the interview, e.g., the mood of the participants, the components they emphasise the most, and any other relevant aspect.

2.4 Digitalisation of maps

FCM was elaborated on A3 with sticky notes, which helped draw the network and move the concepts around. Pictures of the original FCM are displayed in Annex 5. However, the resulting networks were often complex, disorganised, and difficult to understand. To improve clarity, we made digital records of each FCM using the online app Mural, where we rearranged the concepts and corrected spelling mistakes (Annex 6).

Besides the graphical representation, FCMs can also be treated as adjacency matrices, which allow further analysis. Each FCM was uploaded to the Mental Modeler software, which elaborates the matrix and computes basic network metrics (see Annex 10 for the original matrices network metrics). Obtained adjacency matrices for each map can be found in Annex 8.

2.5 Storyline and Analysis

FCM represent the participant's understanding of the system. However, during the interview, the participant may have emphasised certain components more than others or discussed aspects not captured in the graphical representation. To address this, we summarised the interview transcripts into concise narratives (storylines) highlighting the main factors affecting health mentioned by the participant and the key points of their cognitive map. Transcripts were obtained using Gladia AI audio transcription. Additionally, using notes taken during and after the interview, we conducted a brief analysis of the discussed topics and the interview process, including the interviewer's observations (e.g., Was the participant comfortable with the methodology? Did they have a lot to contribute? Did they appear confident when discussing the

components?). Storylines and analysis are displayed in Annex 7. Storylines were compared among the different FCMs to obtain the main themes, as done in Castro et al. (2023).

2.6 Homogenisation of individual maps

Once we had all the individual matrices, we homogenised the variables from individual maps. In the interviews, each participant addressed the factors affecting health using their own vocabulary, and in many cases, different terminologies were used among participants to refer to very similar concepts. To make the maps comparable, a homogenisation of terminology was conducted throughout them. This was done in the context of an internal workshop of the HOBE team where the objectives were (1) to find a common terminology for the concepts mentioned during the individual interviews and (2) to decide the level of scale, grouping or ungrouping variables according to the resolution that wants to be obtained (Olazabal, Neumann, et al., 2018). A final step consisted of identifying if the homogenised and final variable was referring to or affecting ecosystem, animal, and/or human health. Original and homogenized components were translated from Spanish to English to allow their understanding in both languages. The whole homogenisation process is recorded in the workbench in Annex 9.

During the development of the workshop, we grouped all the variables into different thematic groups to identify which components referred to the same concept. When finding very similar ones, we decided on a common terminology that would reflect the original meaning each participant gave using that component. In a second round, we revised the components again and grouped or ungrouped variables according to the level of resolution we wanted to obtain. In this case study, we chose a highly detailed resolution of the system to capture the interconnections between factors identified by local experts. Our goal was to accurately represent these interlinkages while preserving the detail each expert provided. While this approach ensures that important but highly specific factors are retained, it also increases the complexity of the final maps, making them more challenging to interpret (Olazabal, Neumann, et al., 2018).

Even maintaining a high-resolution level, certain nuances of the original concepts were lost in our homogenisation process; if this was the case, it was carefully indicated in the comment column of the workbench. Additionally, in the homogenisation process, some of the original variables were substituted by terms with the opposite meaning, e.g., in FCM15, "Sleep problems" was replaced by "Healthy sleep patterns". In this case, the polarity of the relations or connections incoming and outgoing from this node had to be reversed, which was also indicated in the workbench (Annex 9). After the concept homogenisations, we computed the adequacy of the sample size following Olazabal, Neumann, et al. (2018). We calculated the accumulated number of components participants mentioned and those that were not duplicated.

2.7 Network structure

The elaboration of FCMs produces structured components and connections that form a cohesive network. Understanding the workings of each network provides us with a picture of how health is configured in the socio-ecological system of the Bay of Plentzia, but this becomes difficult in networks of high complexity. Individual FCM's complexity results from the participant's understanding of the system and capacity to model its components and causal relationships. The complexity of each map can be high, especially if the map's resolution is kept high and components are not aggregated between them. Describing the network structure through matrix algebra tools from graph theory is an approach to unravel the knowledge contained in each map (Castro et al., 2023; Gray et al., 2012; Özesmi & Özesmi, 2004). Here, we analysed the

network structure of homogenised individual maps to compare them between participants and identify collective ideas.

To characterise each map, we observed the number of components, number of connections, type of components, density of the map, and complexity score. Additionally, the components with the highest centralities, indegree, and outdegree were identified. See Table 3 for the explanation of each metric.

Table 3. Table modified from Gray et al. (2014), equations from Castro et al. (2023). Structural metrics that can be applied to matrix forms of FCMs.

Mental Model Structural Measurement	**Description of Measure and Cognitive Inference**
N components	The number of variables included in the model and the higher number of concepts indicate more components in the mental model (Özesmi & Özesmi, 2004).
N connections	The number of connections included between variables; a higher number of connections indicates a higher degree of interaction between components in a mental model (Özesmi & Özesmi, 2004).
Connections/Components	The number of connections is divided by the number of components. The lower the score, the higher the degree of connectedness in a system (Özesmi & Özesmi, 2004).
Driver component	Components which only have "forcing" functions indicate the number of components that affect other system components but are not affected by others (Eden et al., 1992).
Receiver component	Components which have only receiving functions indicate the number of components that are affected by other system components but have no effect (Eden et al., 1992).
Ordinary component	Components with both transmitting and receiving functions indicate the number of concepts that influence and are influenced by other concepts (Eden et al., 1992).
Density	Number of connections compared to number of all possible connections. The higher the density, the more potential management policies exist (Hage & Harary, 1984; Özesmi & Özesmi, 2004). $$D = \frac{C}{N\ (N-1)}$$ *D* = density index *C* = total number of connections within the system *N* = total number of components
Complexity	The ratio of receiver variables to driver variables. Indicates the degree of resolution and measures the degree to which driving force outcomes are considered. Higher complexity indicates more complex systems thinking (Eden et al., 1992; Özesmi & Özesmi, 2004).
Centrality, indegree and outdegree of components	The influence of individual concepts as indicated by positive (+) or negative (-) values placed on connections between components, indicates the conceptual weight/importance of individual concepts on the overall network structure (Kosko, 1986). The higher the value, the greater the individual weight of a concept in the overall model. $$c_i = od(v_i) + id(v_i)$$ C_i = centrality index for variable *i* $od(v_i)$ = outdegree strength of each component, computed by adding the absolute value of all connection weights pointing away from component *i* and connecting to other components $id(v_i)$ = indegree strength of each component, computed by adding the absolute value of all connection weights pointing toward component *i* from other components

Results

Following the interviews, several results emerged from the analysis of the FCMs. We reviewed the transcripts and interviewer notes for each session to identify the main topics discussed and the unique perspectives contributed by each participant. The FCMs were then standardised into Homogenised Cognitive Maps (HCMs) to enable direct comparison. This process allowed us to evaluate the structural network metrics of each HCM and determine which health domain—animal, human, or ecosystem—they primarily addressed.

3.1 Individual interviews

We obtained 17 FCMs elaborated between March and May 2024. Each participant built an FCM with the help of the interviewer, who wrote down the participant's ideas and suggested an organisation of the concepts mentioned on the blank paper. The hand-drawn maps created during the interviews are included in Annex 5. All maps were digitalised (e.g. Figure 1) and can be found in Annex 6. Interviews lasted from one to two hours, and the maps contained between 26 and 53 components and 33 and 77 connections.

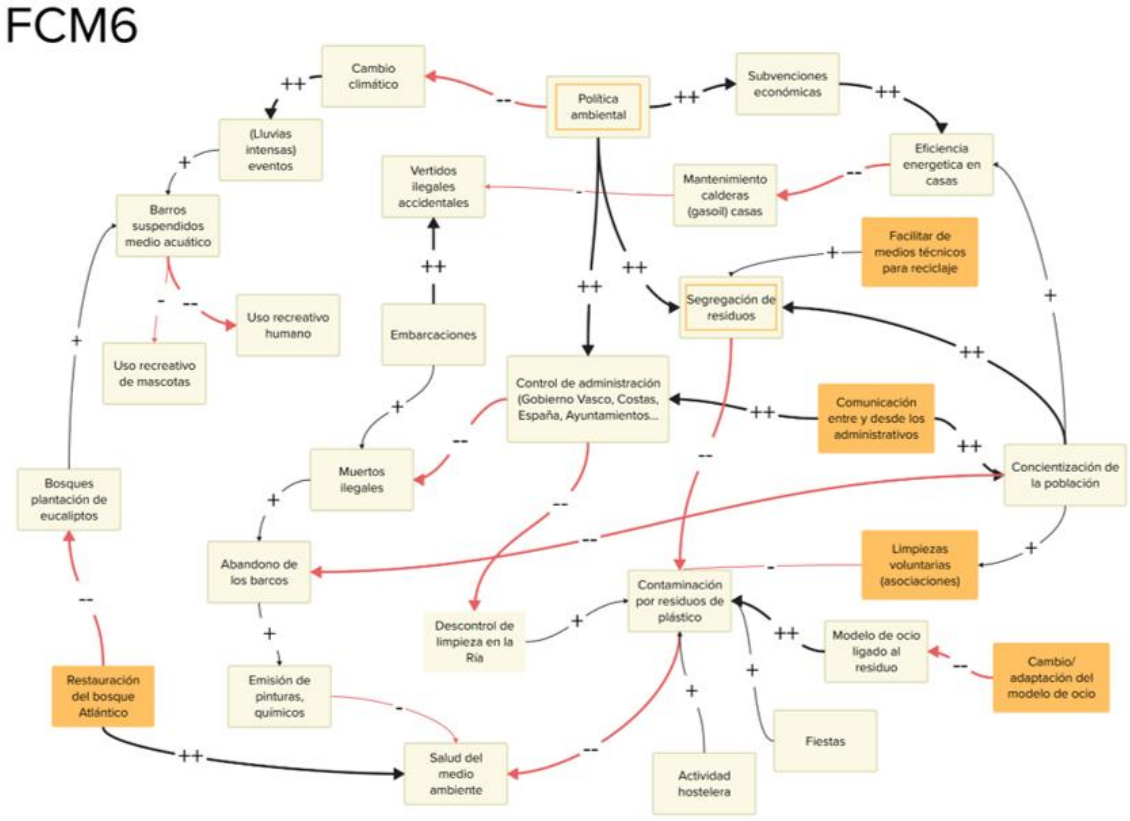


Figure 1. Example of a digitalised FCM using Mural[4].

The stakeholders who participated in the study have a strong connection to the Bay of Plentzia, either through their professional roles or because they reside in the area. Over half of the participants live in the Bay of Plentzia region, and 65% reported spending more than 25% of their

[4] https://app.mural.co/

daily time in or around the area. Only three interviewees indicated they do not interact daily with the Bay of Plentzia, visiting it only occasionally.

While research professionals were the most represented group among the participants (Figure 2), others included members of local associations, healthcare systems, local authorities, enterprises, and veterinary medicine. Notably, one participant (Participant 6) is affiliated with both a local authority and a research centre. The participants come from a wide range of disciplines, including natural sciences (e.g., ecology, microbiology, marine biology, and biochemistry), health sciences (e.g., general medicine and mental health), and socio-economic fields (e.g., tourism and economics). Their expertise also spans nexus areas such as water sanitation, waste management, and coastal environment management. For more detailed information about the participants, refer to Annex 2.



Figure 2. Proportion of type of agents participating in the interviews and their field of expertise.

All participants showed interest in participating in the interviews but responded differently to the questions and the proposed methodology. When asked to assess the HSES of the Bay of Plentzia from an integrated perspective, many participants highlighted that their expertise was confined to a single discipline, which limited their contributions to perceptions based on their specialised knowledge.

Among the 17 participants, five explicitly stated that they were more comfortable discussing topics within their area of expertise (Participants 2, 3, 4, 10, and 15). However, as the interviews progressed, most participants acknowledged that many of the factors they identified were likely interconnected with other disciplines and health domains. This interdisciplinary awareness is reflected in their finalised FCMs, where the components of the networks encompass not only their primary domain of expertise but also elements from other health domains in varying proportions. Annexe 10 illustrates this, showcasing the network characteristics of the FCMs and HCMs alongside the proportion of components addressing each of the three health domains in every map.

Some participants expressed dissatisfaction with the methodology and the phrasing of the questions. Participant 12, for instance, found it challenging to engage with the task, as they believed that nearly everything could be considered to impact the health of the Bay of Plentzia. They felt uneasy about identifying only the "most important" or "influential" factors, drawing a limited number of connections, or assigning greater weight to some over others.

The process of assigning weights to connections resulted from a complex task throughout all the interviews. On the one hand, it corresponded to the final portion of the interview, where participants frequently exhibited signs of fatigue or cognitive overload. On the other hand, assigning weights to connections based on their strength proved especially challenging, as it

required a high level of abstraction to analyse the map and compare connections relative to one another. To guide participants, the interviewer emphasised that the connections should be evaluated within the specific context of the Bay of Plentzia, focusing on their relevance and strength in that particular system and its surroundings. Additionally, the interviewer suggested a step-by-step approach: analysing one component at a time and assigning weights to its incoming and outgoing connections in relative terms. This strategy simplified the task and provided participants with a clear starting point to reduce the risk of feeling overwhelmed. Despite these measures, participants often expressed uncertainty about assigning weights to specific connections. In such cases, interviewers advised defaulting to lower weights to reflect this uncertainty. Consequently, the final connection weights captured both the strength of interactions within the Bay of Plentzia's context and the degree of certainty the participants felt about each connection.

Emerging themes and actions in the HSES of the Bay of Plentzia

During the interviews, participants shared their perspectives and expertise on how the health of animals, humans, and ecosystems is shaped within the socio-ecological system of the Bay of Plentzia. As the interviews progressed, certain topics repeatedly surfaced, with participants consistently emphasising specific issues. By analysing the transcripts and interview notes, we identified six key themes that appear to play a significant role in shaping the Bay's overall HSES. Additionally, we recognised five categories of actions that were frequently suggested across participants (Figure 3).

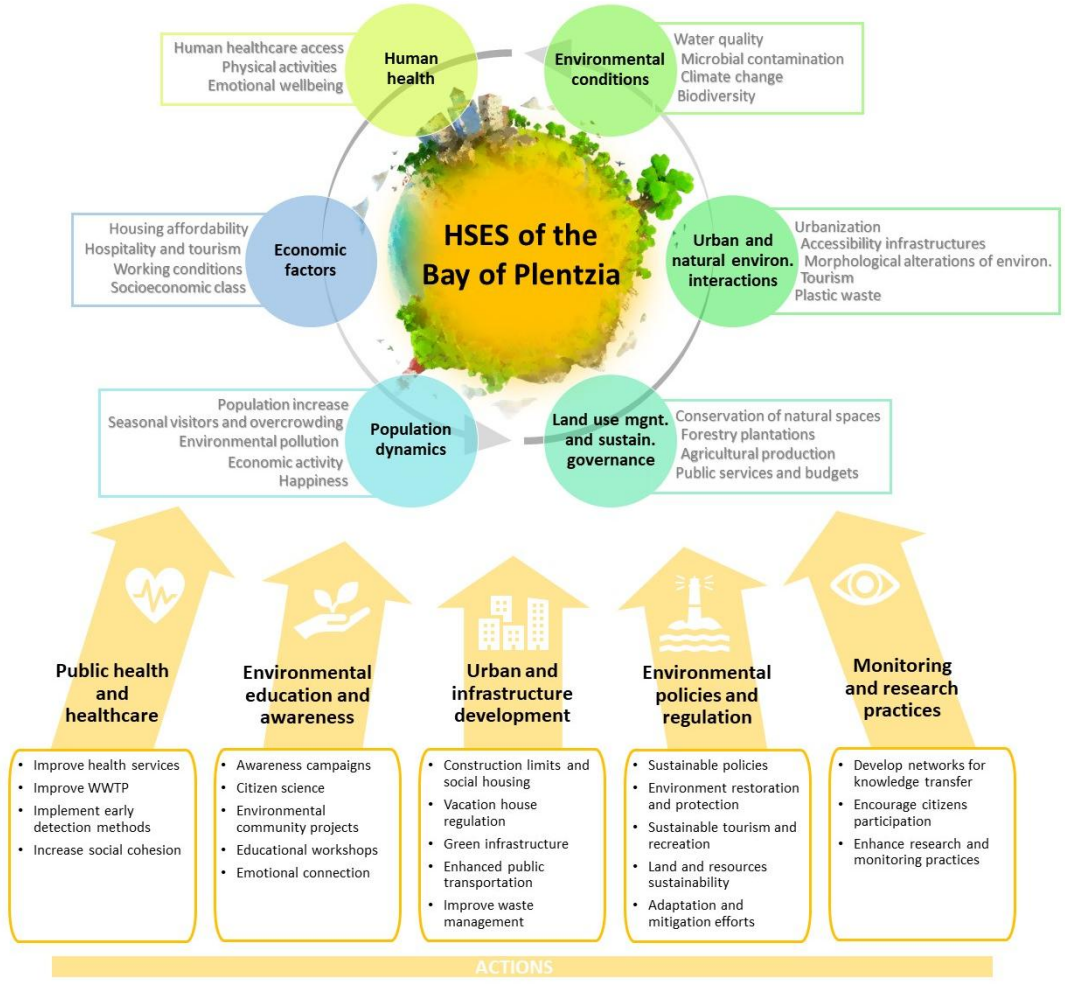


Figure 3. Emerging themes shaping the HSES of the Bay of Plentzia and main actions to improve the situation mentioned during the interviews by the participants.

Emerging themes

1. Human healthcare access, physical activities and emotional well-being

When asked about health from an integrated perspective, only two participants stated that they feel more comfortable focusing primarily on human health (FCM2, FM15). However, in almost all interviews, factors influencing **human health** appear as an undeniably important fraction of configuring the system's overall health. **Ensuring access to quality healthcare services**, both mental and physical, is seen as an important factor (FCM1, FCM14). Nevertheless, participant 15 mentions that it is true that part of the population in the area is characterised by a **rural culture**, with a **resilient attitude towards illness** and a habit of using **home remedies and care** before going to health centres (FCM15).

In the Bay of Plentzia, the existence of the **SOAF**[5] coordinates physical activities and physical therapy assistance to the neighbours of Gorliz (FCM2). **Proximity to green and blue spaces** is also seen as a promoter of human health. On the one hand, they allow physical activities and sports – **hikes, surfing, SUP** (Stand Up Paddleboard) – which **prevent sedentary lifestyles** (FCM2, FCM4, FCM5, FCM14). Besides their physical benefits, these activities contribute to better **mental health**, fostering a **sense of belonging** and enhancing **social health** (FCM2, FCM5, FCM8, FCM16). Nevertheless, open-air activities also have a counterpart in the local system of the Bay of Plentzia. Activities developed in bathing water bodies have often **exposed local residents to environmental pathogens** (FCM7, FCM9, FCM10, FCM11, FCM13, FCM16). For example, Participant 10 mentions the case of surfers who frequent the beach during the winter months, when the wave conditions are favourable. During these months, the responsible administrations do not monitor the Bay's waters, leaving surfers and other swimmers exposed to infections and resulting in **gastrointestinal and dermatological issues**.

Many participants also find **tranquillity**, **relaxation**, and **security** in the natural areas surrounding the Bay (FCM1, FCM5, FCM16) and a **sense of identity** relevant to their personality and conception of themselves (FCM8). Although overall, the natural areas are seen as a factor in improving mental health, they are also associated with **isolation** and **loneliness**, especially for vulnerable collectives such as elderly people or individuals without **access to private transportation** (FCM2, FCM15, FCM16). The **COVID-19 pandemic** is also present in some interviews, where participants attribute to these planetary crises the development of mental issues such as **demotivation**, **depression**, **loss** and **sadness** (FCM2, FCM16).

Participants' perceptions of human health ranged from commonly known factors such as **genetic conditions** or **healthy dietary habits** to socioeconomic factors such as **work conditions** or the existence of **activities offered for young people**. Some participants also pointed out other broader and more transformative issues, such as the **limitations of the current health vision** and conceptualization (both for humans, other organisms, and the environment) and the negative repercussions it can have on humans, animals, and ecosystems (FCM12).

2. Environmental conditions

Environmental conditions are another fundamental pillar in many of the interviews conducted. Although only three participants stated at the beginning that their professional knowledge is limited to environmental disciplines (FCM3, FCM4, and FCM10), most of the interviews include **environmental conditions** as an important determinant of the health of the Bay of Plentzia. In

[5] Physical Activity Guidance Service, for its acronym in Spanish SOAF – *Servicio de Orientación para la Actividad Física*.

the Bay, certain environmental conditions impar the health of humans, animals, and the overall ecosystem.

Water and **aquatic pollution** appear in many of the interviews. Water contamination from **industrial accidents**, **agricultural runoff**, **illegal discharges**, and **untreated wastewater** degrades water quality. In the Bay, there is the **Gorliz Waste Water Treatment Plant** (WWTP), which, since its opening, has significantly contributed to the sanitation of the local aquatic environment (FCM7). Additionally, upstream, there is the **Mungia WWTP**, which also treats the waters of the Butroe River. However, the treatment capacity of both these WWTPs has its limitations. Under certain circumstances (e.g., high flow volume due to **extreme rainfall**), they are forced to release untreated wastewater to the environment, with its impacts on human, animal, and ecosystem health (FCM3, FCM4, FCM6, FCM7, FCM9, FCM10, FCM11, FCM13, FCM17). The Butroe River is not the only source of water pollution in the Bay since several **unmonitored streams** flow into the bathing waters of the Bay (FCM7, FCM9). Additionally, the **water renewal time** in the Bay is rather long due to its **enclosed geomorphology**, which prevents the rapid dilution of pollutants (FCM7).

Microbiological contamination can generate infections in humans and other organisms (FCM 10, FCM16). At the same time, **emerging pollutants**, such as **microplastics** (originating in plastic waste production), **personal care products**, and **pharmaceuticals**, can have other consequences. These include the proliferation of **harmful algae** (FCM13), the increase of **antibiotic-resistant bacteria** (FCM4, FCM11, FCM13), and **chemical toxicity** in the aquatic environment (FCM7, FCM8, FCM10), which threaten the Bay's delicate ecosystem and impact animals and humans.

On the other hand, **climate change** has also been mentioned several times as a factor influencing the HSES of the Bay of Plentzia (FCM3, FCM6, FCM7, FCM13, FCM16). **Rising sea levels**, **warmer nights**, and **extreme weather events** contribute to shifts in the ecosystem, introducing **new bacteria and viruses** (FCM16) and **impacting urban infrastructures** (FCM11). The local climatology also affects residents since some participants relate **sunny and warm conditions** with improved mental health conditions (FCM5, FCM16). While rainy conditions can worsen moods, **extreme precipitation** is also related to the overflowing of the WWTP capacity, as has been seen before, which has potential consequences for physical health. Finally, many participants believe that **biodiversity** plays a crucial role in the ecosystem's health. Since the ecosystem sustains humans and animals in several ways (e.g., **food resources**), it also impacts their health. Throughout the interviews, biodiversity is mentioned for **animals**, **plants**, **algae**, **bacteria**, and **fungi** (FCM7, FCM8, FCM13, FCM9), and it is given high importance for maintaining **population dynamics** and **ecosystem balances** (FCM17). **Invasive species** in the area, such as the zebra mussel and the pampas grass (FCM17), and activities like **fishing** and **shell fishing** (FCM4, FCM3), can disrupt the balance of native flora and fauna (FCM3, FCM17). **Native forests**, like the original Atlantic oak forest of the area, also enhance the identity of locals due to their historical and cultural significance (FCM8).

3. Urban and natural environment interactions

We have already seen how the river, the estuary, the sea, and the hills of the Bay of Plentzia are important factors determining the HSES of the area. However, these environmental conditions are closely intertwined with the presence of **urban spaces**, especially in the urban centres of Plentzia and Gorliz. On the one hand, **blue and green natural spaces** provide benefits for both physical and mental health; on the other, urban spaces and their associated infrastructure allow **accessibility to healthcare centres** and other services. Besides that, relevant interactions are

established among these two environments, from which new factors that determine human, animal, and ecological health emerge.

The development of urban centres is associated with the construction of **buildings and infrastructures**, which unavoidably leads to the degradation of the natural environment (FCM3, FCM17). Over-urbanization and **massive tourism** can harm the environment (FCM1, FCM7, FCM12, FCM14, FCM16, FCM7). The beaches of Plentzia and Gorliz themselves are **artificial urban beaches** that have replaced the original rocky bottom seafloor (FCM17). River-side urbanisation and the construction of dams have led to **morphological alterations of the river**, impairing its **connectivity** and reducing **habitat** and living organism **diversity** (FCM3). The road that used to run along the coastline was replaced by a **waterfront promenade** and areas designated for **environmental restoration** (such as the dune ecosystem), which has encouraged physical activity among the elderly and their pets and improved the health of the surrounding environment (FCM2, FCM4). Additionally, urban infrastructures and public transport enhance the **access of minority groups** (elderly, people with reduced mobility) **to the natural areas** (FCM17, FCM14). These infrastructures on the coastline are also exposed to extreme events such as flooding episodes, strong waves, or sea level rise, with potential **economic consequences** for the local communities (FCM11)

The **Gorliz hospital**, a palliative care centre (FCM10), along with upstream **industries** in municipalities like Mungia and Gatika (FCM5, FCM14), contribute **wastewater** to the urban sanitation system, which may contain specific pollutants such as pharmaceuticals and industrial chemicals—either through **regulated discharges** or **accidental releases** (FCM5, FCM7, FCM10). While the wastewater is processed at the WWTP, its contents can still affect local ecosystems. Additionally, urban areas, with their residents and visitors, generate significant amounts of **waste**, particularly plastic, which poses a threat to the health of ecosystems, animals, and humans (FCM4, FCM5, FCM6, FCM10, FCM15, FCM16). Microplastics, for instance, can serve as a surface for accumulating pollutants and bacteria, including antibiotic-resistant genes (FCM10).

4. Land use management and sustainable governance

Besides the interactions between natural and urban spaces, the **land use** in the Bay of Plentzia and the Butroe River also emerges as a recurring theme in the interviews. The nature and characteristics of the different activities developed in the nearby lands can impact the status of the ecosystems and have consequences on human and animal health.

Regarding urban spaces, Participant 1 mentions the existence of **construction restrictions** in the latest Gorliz PGOU[6] (FCM1) to reduce impacts on the natural environment, and Participant 12 highlights that **land use planning** should consider health in all its dimensions, **including conservation and connectivity of natural spaces**, **wildlife biodiversity**, and **agricultural production** (FCM12). The type of agricultural practices and how soil is managed in the area also raise concerns for many participants. **Txakoli crops** and other **agricultural activities** can affect the quality of the river water if they use pesticides and polluting phytosanitary products (FCM3, FCM9). Pine and eucalyptus **forestry plantations** in the watershed are also perceived as partially responsible for poor water quality due to their extractive characteristics and consequences on **soil erosion** (FCM3, FCM4, FCM6, FCM12). Additionally, Participant 12 establishes a link between the extension of forestry plantations and the land left for agricultural food production. In the area, eucalyptus plantations reduce the availability of fertile soil and complicate the establishment of croplands (FCM12). The presence of **local food systems** is also considered in

[6] PGOU: its acronym in Spanish of Plan General de Ordenación Urbana [General Urban Development Plan]

FCM12 and FCM13 as a factor supporting residents' health. On the other hand, although none of the participants mentioned intense livestock activity in the area, some included **cattle**, **horses**, and **sheep** as potential sources of water contamination if their waste is not managed properly (FCM4, FCM7, FCM9).

Local and regional institutions are responsible for the **governances** established in the area. For this reason, many participants consider that the type of governance implemented has strong consequences for the system's health. **Public entities' budgets** are allocated to conserving and restoring natural spaces (FCM14, FCM17). In contrast, another part is dedicated to **public amenities** such as beach restrooms, cleaning services, or public transportation (FCM14), which improve the population's overall well-being. Institutions are also responsible for establishing the **PGOUs** and land use plans and implementing **sustainable governance** practices and **environmental controls** (FCM3, FCM6, FCM17).

5. **Population dynamics**

Because of its location and characteristics, the Bay of Plentzia has a particular population dynamic, which affects the system's stability. Over the past years, the towns in the area have experienced a **population increase** (FCM7, FCM9), especially among **new young families**, who are mainly attracted by the proximity to nature, the open-air lifestyle, and the various physical activity offerings (FCM1, FCM5, FCM14, FCM15, FCM17). Additionally, population **peaks in the summer, weekends and holidays**, when visitors and seasonal residents come to the Bay to enjoy the beaches and other natural spaces (FCM11, FCM12, FCM14).

This situation has led to an increase in the overall demand for WWTP or healthcare services. The influx of tourists and temporal residents, especially during peak seasons, can lead to overpopulation and overcrowding, which places a **higher demand on local resources and infrastructure** (FCM7, FCM14). The presence of **touristic** and **recreational activities** has led to morphological alterations of the river (FCM3), **increased waste production**, especially plastic (FCM6, FCM10, FCM16), the **degradation of protected habitats**, and an overall **decrease of biodiversity** (FCM3). Plastic litter can break down into microplastics, which can have consequences for the health of wildlife in the area (FCM16). Recreational activities like barbecues or the increased number of vehicles contribute to **atmospheric pollution**, further stressing the natural environment and harming people with respiratory conditions such as asthma (FCM4, FCM14). Furthermore, the population increase in nearby areas such as Mungia and Gatika raises the demand for upstream water treatment, which could exacerbate pollutant pressures on the Bay.

It cannot be forgotten that the presence of visitors and newcomers brings **activity**, **economic benefits**, and **joy** to the localities, especially because it coincides with the seasons of better weather, sunshine and warmth (FCM1). However, **overcrowding** can disrupt the ecological balance of the Bay and cause **stress** among residents, which in turn leads to **emotional instability** in many of the inhabitants (FCM16).

6. **Economic factors**

Besides governance structures, healthcare accessibility, population dynamics, etc., there are other factors that were given importance by some participants and that are related mostly to **economic factors**.

Tourism has been mentioned in the previous section in relation to its effects on population dynamics. However, it also stimulates the **hospitality sector** (bars and restaurants) and

recreational activities (FCM14, FCM16). If the number of summer visitors decreased, the local economic activity would be affected (FCM11). On the other hand, if tourism is not regulated and the demand for vacation rentals continues to rise, **housing** may become inaccessible to residents, which is already occurring today and is affecting their well-being (FCM14, FCM17). **Unemployment** is also seen to impact human health (FCM14) negatively, but health can also be affected if **working conditions** are not good. Precarious working conditions can generate **musculoskeletal problems** (e.g., in a highly physically demanding job) or lead to **anxiety** and **depression disorders** (FCM15). Limited **financial resources** can also mean an inability to maintain **nutritionally healthy diets**, affecting physical health (FCM2, FCM15). Participant 15, however, considers the socioeconomic level of the area as middle-high when compared to other parts of Biscay.

On the other hand, the insufficiency of **public transportation** is mentioned several times, both in terms of diversity and frequency. Certain areas remain isolated or have difficulty accessing, which poses a problem for some residents, especially **elderly** and **house caregivers**, without access to private transportation. This adds to other factors affecting their mental health (FCM13, FCM15).

Finally, participant 11 also highlights that the area's economic system is under pressure from **global and local environmental change**, which can lead to a decrease in happiness and, therefore, overall well-being in the Bay (FCM11).

Actions that can be implemented to improve the HSES of the Bay of Plentzia
Nearly all participants proposed actions to improve the situation in the Bay of Plentzia. The only exception was Participant 7, who felt there were no specific actions that could enhance the Bay's health and, as a result, did not include any in their map.

1. **Public health and healthcare**

Since one of the main themes was human healthcare, many actions suggested by participants were directed to **improve healthcare services**. Some participants stressed the need for coordination between different healthcare resources and services (FCM15), and others highlighted the need to **allocate more healthcare resources to mental health** (FCM11). Some others also mentioned the need for increased **physical activity promotion**, especially from municipalities, and the benefits of structures like the SOAF in Gorliz to improve overall human health (FCM1, FCM2, FCM5). The **economic promotion** of healthy food (FCM2) and local food systems (FCM12) is also highlighted. Because of the local characteristics of the area, Participant 15 highlights the importance of a **strong relationship between the patient and the healthcare professional** (FCM15).

Improving the WWTP's capacity or implementing cutting-edge technologies to improve its functioning is also suggested to foster better public, animal, and ecosystem health (FCM4, FCM9, FCM11). Some participants believe that avoiding episodes of microbiological contamination resulting from the overloading of WWTPs is highly complicated and suggest **implementing efficient early detection methods and alert systems** to avoid human exposure to contamination (FCM9, FCM10).

Increased social cohesion through education, community projects, and activities offered for young people and the elderly would strengthen social networks and the overall community well-being (FCM1, FCM8, FCM13, FCM15). **Create information and communication networks** (FCM13), both between administrations and with research centres, other institutions, and the public (FCM6), **positively sharing information** to ensure it is better received (FCM16).

2. Environmental education and awareness

Education and **awareness campaigns** appear to be an action in many interviews. Raising public awareness is considered a strategy to improve the health of the environment, its ecosystems and the animals (FCM5, FCM8, FCM14, FCM17). In the Bay of Plentzia, participants mention there are campaigns for the control and eradication of invasive species (FCM3), for the reduction and better management of waste (FCM5), and for responsible use of pharmaceuticals and fertilisers (FCM11, FCM15). On the other hand, **involving the community in local science and research projects**, as well as implementing **environmental community projects**, can encourage awareness and respect for the environment, which contributes to its health and that of its inhabitants (FCM 8, FCM14, FCM16, FCM17).

Participants 8 and 17 emphasise that investing in education for all ages through **workshops** in local schools and high schools is an essential step to raising awareness about the issues related to human, animal, and ecosystem health that may exist in the Bay (FCM8, FCM17). Additionally, participant 16 suggests that **tangible, practical environmental education** is the best strategy to foster environmental awareness by generating an **emotional connection** with nature (FCM16).

3. Urban and infrastructure development

Another important group of actions refers to urban development and infrastructure construction. PGOUs define the key characteristics of urban centres, and the most recent plan approved in Gorliz enforces significant **construction restrictions** to protect the environment (FCM1). While these measures help safeguard the area's natural habitats and species, the region's high tourist activity drives up housing costs, making it less affordable (FCM1). As a result, Participant 14 highlighted the need for **social housing** (FCM14). Effective administrative oversight and **regulation of vacation homes** are also considered essential actions for the proper health of the system (FCM17).

Other actions include the **construction of more infrastructures and facilities to promote health** (FCM15). Global changes, such as climate change, will likely affect the Bay's urban centres and infrastructure, highlighting the need for effective **mitigation and adaptation plans** (FCM11). Extreme flooding events, for instance, threaten the seafront walkways in Gorliz and Plentzia (FCM11), which many participants regard as crucial for promoting physical activity and human health (FCM3, FCM15). Heatwaves also pose risks to both human and animal health. To address this, Participant 3 recommends **increasing vegetation** along the walkways to provide shade and create a cooling microclimate (FCM4). This greenery could also enhance human microbiota by fostering greater microbial diversity in the environment (FCM4). Additionally, **converting paved surfaces**, such as parking lots, **into porous surfaces** could help reduce heat retention, improve soil permeability, and contribute to overall soil health (FCM4).

Many participants believe that public transportation could be enhanced in terms of **frequency and availability** (FCM1, FCM4, FCM14, FCM17). Similarly, waste management is seen as an area needing improvement. Suggestions include implementing **better segregation practices** (FCM6), **providing technical support for recycling** (FCM6), and **increasing the size and number of waste containers** (FCM10). Additionally, there is a call for **stronger waste legislation** (FCM4, FCM16). Efforts should also be directed towards **transforming the current leisure model**, which is heavily tied to waste generation, particularly plastic waste, into a more environmentally conscious one (FCM6). Furthermore, to reduce pollutant loads, participants frequently emphasise the need to **limit the use of antibiotics, pharmaceuticals, and fertilisers** (FCM3, FCM15, FCM11).

4. Environmental policies and regulations

The role of local administrations is seen as crucial in shaping the health of the Bay of Plentzia (FCM8). They are tasked with **implementing sustainable and environmental policies** (FCM6, FCM14, FCM16), which include **regulating illegal fishing and shellfish harvesting** (FCM3, FCM4), **controlling invasive species** (FCM3, FCM4), and **launching dam demolition programs** to restore river connectivity (FCM3). Additionally, administrations are responsible for **restoring wetlands** and **other habitats** (FCM3, FCM8) and **reducing CO2 emissions** (FCM11). Local government initiatives have aimed to **de-seasonalize tourism** with activities throughout the year and not only during summer (FCM1). Municipalities are also responsible for **promoting sustainable tourism**, managing human presence in natural recreation areas like beaches to prevent exceeding their carrying capacity (FCM4) and **enhancing environmental awareness** among visitors and tourists (FCM1).

Other sustainable policies also extend to land and resource management. There is a need for more **sustainable forestry practices** in the area (FCM4), alongside efforts to promote and **restore the original Atlantic forest** (FCM6). Agricultural methods could benefit from improvements like **Regenerative Rotational Grazing** (FCM4) and the adoption of **Best Management Practices** (FCM3). Additionally, **fishing quotas** could be implemented for nearby municipalities that fish in the surrounding areas (FCM14). Finally, aquaculture practices and the **local economy** must adapt to evolving environmental conditions (FCM11) and future pandemics (FCM13).

5. Monitoring and research practices

Participants suggested several actions related to **enhancing monitoring and research practices**. Effective environmental management depends on robust monitoring, research, and knowledge networks (FCM13, FCM14, FCM17). For instance, it is crucial to **assess changes in bacteria populations in bathing waters** (FCM11) **and understand the life cycles of products to evaluate their environmental impact** (FCM3). Comprehensive studies and continuous research are vital for managing and controlling environmental impacts, while effective monitoring ensures that changes are properly tracked and addressed (FCM11). **Developing strong networks for information transfer and communication** is key for sharing knowledge among researchers, policymakers, and the public (FCM13, FCM14, FCM17), essential for improving decision-making and gaining public support (FCM13). **Encouraging citizen participation** and scientific communication fosters greater awareness and collaboration, enhancing environmental control efforts' overall effectiveness (FCM13, FCM17). Additionally, multiple participants proposed a more in-depth investigation of the connections outlined in their cognitive maps, suggesting that a **better understanding of these interconnections** could significantly improve the HSES of the Bay of Plentzia. These actions can be seen as separate boxes, not graphically connected to any component, because they address the entire network of factors (FCM11, FCM13).

3.2 Homogenised Cognitive Maps

From the 651 original components identified in the 17 FCMs, the homogenisation process reduced them to 367 unique, non-duplicated components (Figure 4). This process involved recording all terminology changes, grouping and ungrouping concepts, translating terms into English, and noting any reversals of connection signs (detailed in Annex 9). Using these homogenised components, we assessed the adequacy of the sample size. The accumulation curve of unique concepts (shown in blue in Figure 4) continued to rise without stabilizing, even after incorporating all 17 Homogenized Cognitive Maps (HCMs). This indicates that the sample

size may be insufficient, as new components referring to new variables were introduced with each additional map.

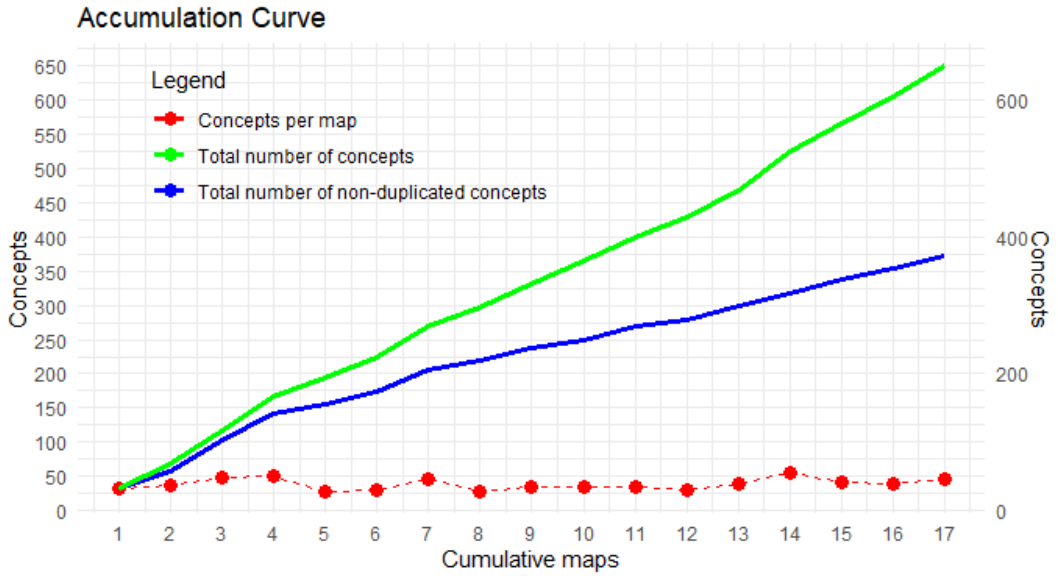


Figure 4. Accumulation curves for the HCMs. Red dots indicate the number of concepts in each HCM. The green line represents the total number of concepts mentioned by participants. The blue line represents the number of non-duplicated concepts accumulated after each HCM.

Each of the obtained 17 HCMs had different characteristics and network structures. The number of components ranged between 27 and 54, and the number of connections was between 33 and 89 (Table 4). When looking at the main network metrics for the HCMs, we found that density values were low for all of them (0.02 - 0.06). Most components building the HCMs were ordinary components (with incoming and outgoing connections); driver components were more frequent than receiver ones. In four cases, receiver components were more abundant, as reflected in the complexity score of HCM7, HCM8, HCM12, and HCM15 (Table 4). In the case of HCM12, it presents a very high complexity score since it only presents one driver component.

Table 4. Network structure of HCMs, i.e., FCMs after the homogenisation process.

	N components	N connections	Density	Connections per component	N Driver	N Receiver	N Ordinary	Complexity score
HCM1	32	40	0.04	1.25	13	6	13	0.46
HCM2	36	55	0.04	1.53	13	5	18	0.38
HCM3	49	71	0.03	1.45	17	10	22	0.59
HCM4	50	58	0.02	1.16	16	13	21	0.81
HCM5	27	45	0.06	1.67	6	3	18	0.50
HCM6	29	36	0.04	1.24	8	4	17	0.50
HCM7	47	68	0.03	1.45	11	11	25	1.00
HCM8	27	33	0.05	1.22	6	9	12	1.50
HCM9	34	46	0.04	1.35	13	6	15	0.46
HCM10	34	36	0.03	1.06	12	4	18	0.33
HCM11	35	55	0.05	1.57	10	3	22	0.30
HCM12	28	47	0.06	1.68	1	12	15	12.00
HCM13	40	68	0.04	1.70	11	9	20	0.82

HCM14	54	89	0.03	1.65	19	7	28	0.37
HCM15	41	60	0.04	1.46	9	9	23	1.00
HCM16	39	68	0.05	1.74	8	5	26	0.63
HCM17	47	76	0.04	1.62	13	12	22	0.92

We compared network metrics between FCMs (pre-homogenisation) and HCMs (post-homogenisation) and found no major differences between them (see Annex 10). The number of components remained more or less the same, while connections increased in HCM3, HCM9, HCM12, HCM13, and HCM14 and decreased in HCM15. Density still remained very low but slightly increased in many HCMs. Driver, receiver and ordinary components remained more or less the same, except in HCM12, where receiver components increased from 8 to 12. Finally, the complexity score remained approximately the same in all maps except in HCM12, the map with the highest score, which became even higher (see Annex 10 for more information).

The visual network structure is represented in Figure 5. Each network corresponds to an interview's map after its digitalisation and homogenisation. Colour codes represent the health domain to which the component is referring and the node size corresponds to its centrality: the bigger the node's size, the higher its centrality in the map. Edges show connections between two components; their thickness corresponds to their weight. Network structure differs among interviews, but in most cases, it remains a single network. Only in HCM1, HCM9, and HCM10, the mental models consist in more than one network.

The dominant colours are greyish violet and orange (Figure 5). Greyish violet indicates components that impact the three health domains (ecosystems, animals, and humans, EAH), while orange refers to those that only affect human health. Most networks address health by integrating all three domains and contain components that refer to ecosystems, humans, and animal health. In some cases (HCM5, HCM8, and HCM17), we distinguish two differentiated networks connected by a single edge. In these cases, the two distinguished networks are characterised by referring one to determinants of human health (in orange) and the other to integrated EAH determinants (in violet) (Figure 5). While violet is dominant, we can see that orange components (human health) are dominant in some specific maps. HCM1, HCM2, and HCM15 are the most human health-focused (Figure 5).

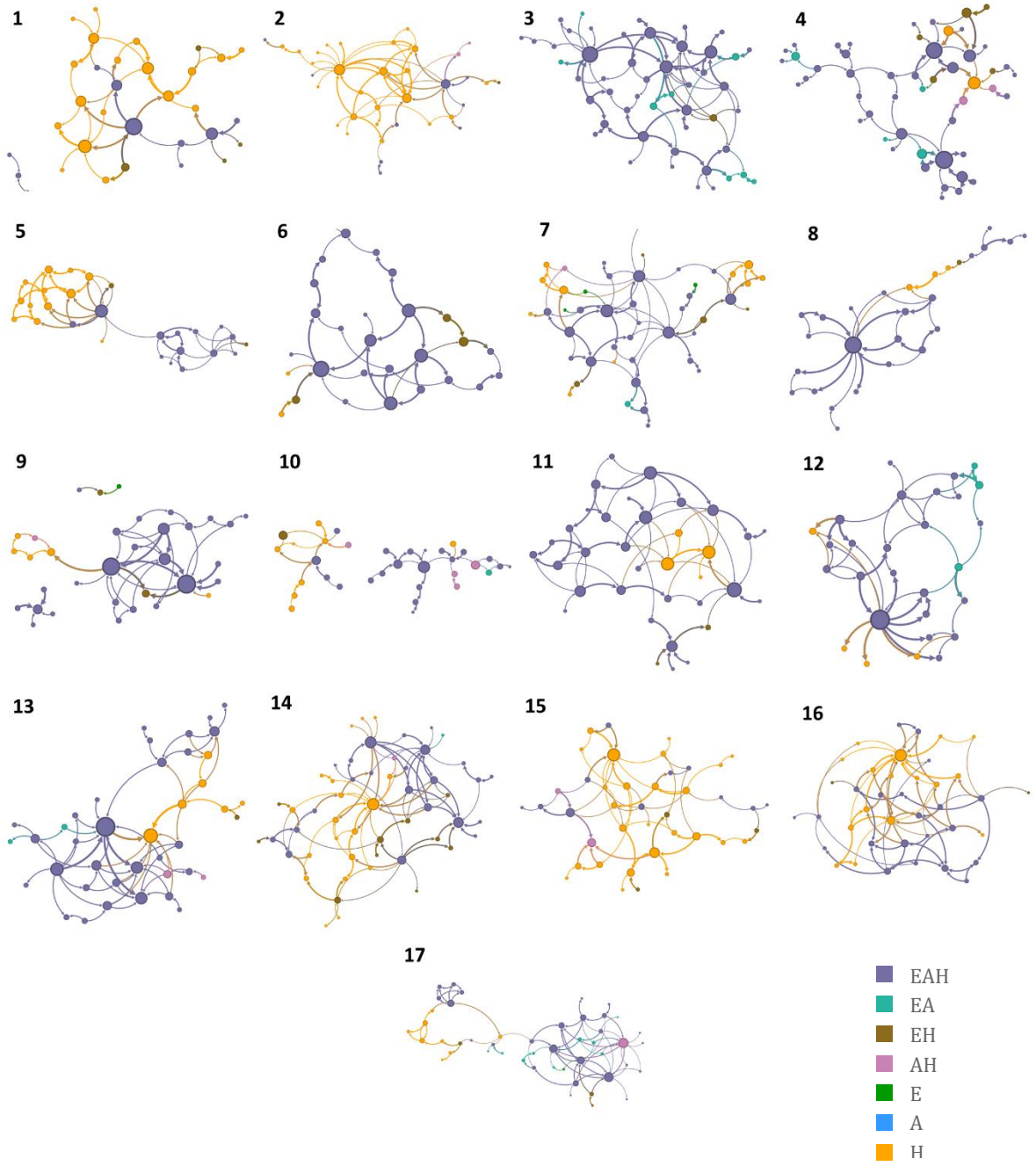
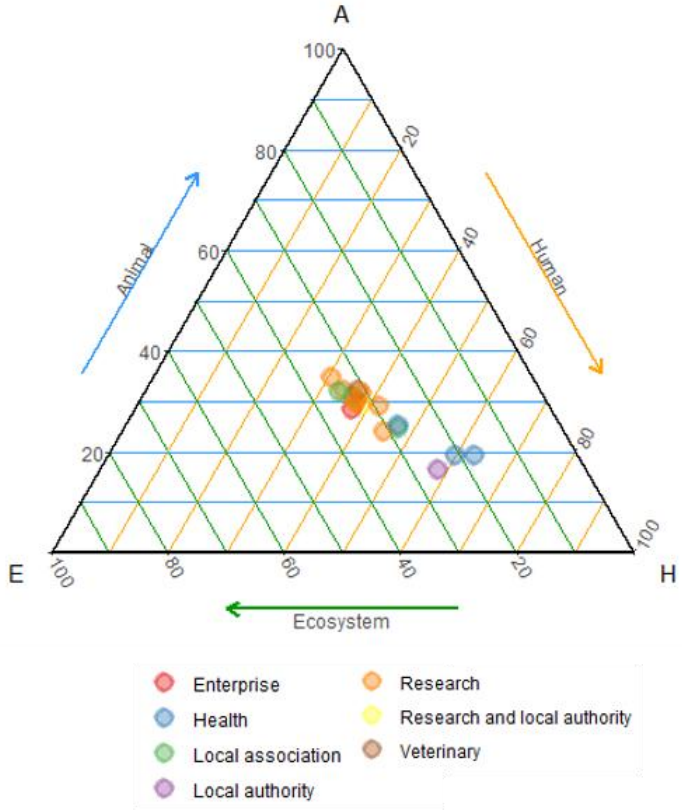


Figure 5. 17 networks obtained per HCMs. Nodes represent components; their size indicates their centrality (bigger nodes, higher centralities). Colour coding refers to each component's health domain (E stands for environment, H for human, and A for animal). None of them address animal health. The edge's thickness corresponds to its weight, and the colour mixes the two connected nodes.

These results can also be seen in Figure 6. The proportion of components addressing human, animal, and ecosystem health in each HCM. Axes of the triangle represent the percentage of components referring to animal, human and ecosystem health domains. Circle colour codes indicate the type of agent, which shows the proportion of each health domain addressed in each HCM. Here, we added the components addressing animal, human, and ecosystem health and calculated the percentages. Most maps are situated near the centre of the triangle, suggesting that their components related to animal, human, and ecosystem health are distributed more or

less equally. All HCM have over 30% of their components referring to human health, while 11 have more than 30% of their components addressing ecosystem health. Only 7 have more than 30% addressing animal health (Figure 6). The closer an HCM is to a specific angle, the more it focuses on that particular health domain. The circle distribution within the triangle is biased towards the human health angle, which indicates that in many maps, more than 40% of the components address human health (Figure 6). The circles closer to the human health angle are HCM1, HCM2, and HCM15. These results correspond to those seen in Figure 5.



HCM	Agent	Health domain
HCM1		EH
HCM2		H
HCM3		E
HCM4		E
HCM5		EAH
HCM6		Not specified
HCM7		Not specified
HCM8		Not specified
HCM9		EAH
HCM10		E
HCM11		EH
HCM12		EAH
HCM13		Not specified
HCM14		Not specified
HCM15		H
HCM16		EAH
HCM17		EAH

Figure 6. The proportion of components addressing human, animal, and ecosystem health in each HCM. Axes of the triangle represent the percentage of components referring to animal, human and ecosystem health domains. Circle colour codes indicate the type of agent.

HCM1, HCM2, and HCM15 belong to maps from a local authority and two health practitioners, respectively (Figure 6). In this case, their results correspond to what they declared at the beginning of the interview: the health domain they felt comfortable addressing corresponded to their area of expertise, human health-related issues (and the health of the ecosystem in the case of HCM1). However, in many other cases, participants mentioned that they felt more comfortable speaking about their area of expertise but ended up addressing health in an integrated way, as can be seen by the positioning of most circles in Figure 6's triangle. Five participants initially chose not to select any specific health domain, and their maps reflect a more balanced combination across the three domains. Three participants preferred focusing on ecosystem health but inevitably included elements impacting both animals and humans. Two participants felt comfortable discussing a blend of human and ecosystem health, while five emphasised the importance of addressing all three domains right from the beginning (Figure 6). Interestingly, the only maps with more components addressing areas other than human health were HCM3, elaborated by a researcher, and FCM17, developed by a local association representative. None of

the participants chose to focus their map exclusively on animal health, which led to components related to animal health being the less represented ones (Figure 5 and Figure 6).

Finally, we also observed which components were the most influenced and influenceable in the HCMs and compared them. To do so, we calculated each component's centrality, in-degree, and out-degree, identifying those with the highest values (Table 5). Components in the centrality column correspond to the larger circles in the networks of Figure 5. In cases where multiple components shared the highest centrality, all were included.

Table 5. Components with the highest centralities, in-degree and out-degree, in the HCMs. If more than one component is displayed, they share the highest value.

HCM	**Centrality**	**In-degree**	**Out-degree**
1	Ggreen and blue spaces	Mental health	Green and blue spaces
2	SOAF[7]	Physical health	SOAF; Hikes
3	Emerging pollutants	Aquatic biodiversity	Coordination and communication between and within administrations
4	Terrestrial biodiversity	Terrestrial biodiversity; Microplastics	Livestock farming
5	Contact with blue and green spaces	Physical health; Human health	Contact with blue and green spaces
6	Pollution from plastic waste	Pollution from plastic waste	Implementation of environmental policies
7	Physico-chemical treatment of water at the WWTP	Physico-chemical treatment of water at the WWTP; Water quality	Sunny and warm climate
8	Water quality	Water quality	Water quality
9	Water quality	Water quality	Rainfall
10	Acute gastrointestinal infections	Acute gastrointestinal infections	Coliform bacteria; Microplastics
11	Impacts in urban areas	Impacts in urban areas; Happiness	Increased sea temperature
12	Education for better knowledge of one's own health	Agricultural diversity	Education for better knowledge of one's own health
13	Microbiota health	Human health	Climate change
14	Human health	Human health	Provision of public services for Plentzia Bay
15	Activity of the health centre	Activity of the health centre	Precarious working conditions
16	Mental health	Mental health	Emotional connection with nature
17	Water pollution	Aquatic biodiversity	Institutional and budgetary resources available for Plentzia Bay

Discussion

In this study, we want to investigate which factors shape the HSES of the Bay of Plentzia and its surroundings. After reviewing the available literature, which mainly consists of institutional reports (see D2.1, Chapter 3), we focused this research on situated knowledge (Haraway, 1988), i.e., knowledge from those who experienced the system first-hand. Here, we suggest a strategy to collect multiple and diverse perspectives by interviewing local experts and stakeholders and collectively drawing their mental models of the system into consideration. Each mental model represents the system's workings according to each interviewee's understanding, background expertise and personal perceptions (Gray et al., 2015). We considered factors determining the health of humans, animals, and the overall ecosystem to address the HSES of the Bay from a One Health perspective (Zinsstag et al. 2011). Experts with different fields of expertise and disciplinary backgrounds were contacted and participated in the interviews. By involving

[7] Physical Activity Guidance Service, for its acronym in Spanish SOAF – *Servicio de Orientación para la Actividad Física*

participants from different domains, we approach health from diverse perspectives and combine a multiplicity of knowledge to represent an integrated HSES of the Bay of Plentzia.

3.1 Methodological observations

Throughout the interview process, most participants actively engaged and responded positively when elaborating on their cognitive maps. Some of them asked to take a picture of their cognitive map once it was finished. By not predefining the health domain in the initial question, participants were not constrained by their professional background, allowing them to discuss familiar aspects that might extend beyond their discipline. This was evident in many interviews and is reflected in the resulting FCMs, which incorporate factors impacting all three health domains. Additionally, this open-ended approach fostered a supportive environment where participants felt comfortable sharing insights, including those rooted in personal perceptions. As a result, the outcomes from each participant represent a unique integration of their professional expertise as experts and personal knowledge as residents of the Bay of Plentzia. It is important to emphasize that the cognitive maps generated are specific to the SES environment in which they were developed and may not be directly applicable to other contexts. Nonetheless, the findings and methodology offer valuable insights that can inform studies in other SESs (Schwermer et al., 2021).

Among the participants, only two expressed discomfort with the complexity of the subject matter and the way ideas were being represented on paper. They felt that the issues discussed were too abstract and intricate to be effectively visualized as influence diagrams. The added task of weighting connections further compounded the complexity of the activity. Similar findings were observed in the study by Tepes & Neumann (2020), where participants noted that connections often depended on uncertain circumstances and varied across temporal and spatial scales.

Despite these challenges, most participants felt comfortable acknowledging the subjectivity involved in the activity and expressed interest in the methodology. The majority preferred to focus on the discussion, delegating the task of writing to the interviewer. Following this preference, the interviewer identified key components emphasized by the participants during the conversation and proposed their inclusion in the map. Participants would then confirm or reject these suggestions, after which the interviewer would incorporate them into the diagram. This approach, however, introduced two potential issues. First, the multitasking required of the interviewer could interrupt the conversation's flow, distract the participant, and disrupt their thought process, hindering the interview's overall progression. Second, the selection of components for the map was influenced by the interviewer's subjective interpretation of the participant's input. This added layer of interpretation introduced an external element, potentially affecting the representation's fidelity. To mitigate these effects, the interviewer actively sought participants' feedback, ensuring that proposed components were aligned with their perspectives. Any components that did not meet the participants' satisfaction were either discarded or rephrased to better reflect their intent. This iterative process aimed to minimize interpretative bias and enhance the accuracy of the resulting cognitive maps.

The choice of terminology to describe a factor (i.e., how to label a component) was not always straightforward. In several cases, a participant identified a component that influenced another through multiple pathways, but only highlighted and emphasised one of those pathways. For example, factors such as "Climate change", "Global change", or "Local environmental change"

appear as components in many maps and have a positive or negative interaction with other components. However, in many cases, this effect can happen in both directions, as was mentioned several times throughout the interviews. For instance, in FCM13, an increase in "Climate change" affects "Microbial biodiversity", but it could either reduce or increase it. According to the participant, both outcomes could be possible in the context of the Bay of Plentzia, and a specific study would be needed to explore these processes in detail. None of the participants had empirical knowledge to definitively determine whether the impacts of climate change on microbial biodiversity would be positive or negative. This uncertainty was present for climate change, microbiome diversity, and other components of the network. In response, some participants chose to represent only the connection they deemed most relevant, providing explicit reasoning for the connections they included. Referring back to the example, in FCM13, the participant explained that the original conditions of a natural system, shaped by hundreds of years of evolutionary and interconnected processes, were in their present state due to gradual changes. Abrupt alterations, such as those caused by climate change, could disrupt these original conditions, creating an imbalance in the system. Although the system might eventually adapt and return to stability, Participant 13 depicted – within their cognitive map – that this imbalance would lead to negative consequences for the system, at least in the short term. In FCM13, therefore, the connection between "Climate change" and "Microbial biodiversity" is represented as a negative interaction.

During the cognitive maps' analysis, we wanted to keep the names as similar as possible to the original ones so as not to distort the knowledge reflected by each participant. In the homogenisation of FCMs, we renamed those components referring to practically the same idea into a common terminology, but otherwise, we left them separately. This resulted in highly detailed networks with high levels of fidelity that retained a similar structure to the original ones after the homogenisation, e.g., with comparable density and complexity values (see Annex 10).

When assessing the adequacy of the sample size after homogenisation, we observed that the cumulative curve of non-duplicated components did not level off with the maps created. New concepts appeared in each interview, indicating that additional interviews are required to reach a point where no new concepts are introduced (Olazabal, Neumann, et al., 2018; Özesmi & Özesmi, 2004). This might be related to the level of detail in the components the homogenisation process. In our case, we maintained a very detailed scale to accurately capture the complexity of our specific system. We prioritised preserving a high level of resolution to retain the subtle distinctions added by each participant, rather than grouping components into larger categories. For example, "Water pollution" and "Water quality". Many participants view water pollution as the presence of harmful substances such as chemicals, microorganisms, or waste in water, whereas water quality refers to measuring the physical, chemical, and biological characteristics of water to assess its suitability for various living organisms and ecosystems, including human uses. Maintaining such a high resolution led to a large number of components, preventing the cumulative curve from stabilizing. This choice ultimately decreased the simplicity of the maps, diminishing their interpretability (Olazabal, Neumann, et al., 2018).

Another consequence of keeping high levels of detail is that cognitive maps end up showing components belonging multiple scales, i.e., "Human health" comprises "Mental health" and "Physical health". While we could have group them into a single component, we chose to keep them separate to better represent the specific connections to each one. However, in cases where "Human health" was used as a component, we did not break it down further to avoid making assumptions about which aspect of health the participant was referencing. This raises the issue that connections affecting human health as a broad concept might be scattered into

connections impacting the "Human health" node, the "Mental health" node, and/or the "Physical health" node. For this reason, network metrics of each single component (displayed in Table 5 and Annex 11) might not reflect real implications; for example, HCM14 contains "Human health", "Physical health", and Mental health" as distinct components. Both "Physical health" and "Mental health" are impacted by factors such as "Education for better knowledge on one's own health", "Access to social and healthcare services", and "Genetic profiles prone to diseases". Additionally, "Mental health" is further affected by "Recreational activities". However, none of these components directly impact "Human health", which is influenced by a range of other components in the network. While both "Physical health" and "Mental health" are connected to "Human health", their influence is indirect. As a result, the centrality of "Human health" is not reflected in these connections, meaning that its importance would have been higher if "Physical health" and "Mental health" were grouped together as one component.

The methodology we followed results in complex maps with very low-density values. Many authors suggest aiming for fewer components (no more than 20) to avoid complexity and processing difficulties (Gray et al., 2015; Özesmi & Özesmi, 2004), which could be achieved by further clustering the components. However, resolution was central to our analysis, even though the complexity associated.

3.2 Determining the HSES of the Bay of Plentzia

Most of the participants have a background in research, although there are also some representatives of the healthcare system, the wastewater treatment company, and some local associations. The results reveal that, although many participants came from distinct disciplines, their maps jointly addressed multiple health areas, often covering factors that simultaneously affect humans, animals, and the surrounding environment. However, a significant bias toward human health emerged in many of the maps, as many components exclusively referenced human health concerns. This tendency is particularly evident in maps 1, 2, 5, 14, 15, and 16, created by participants with backgrounds in human health or socioeconomic fields like tourism and economics.

Conversely, maps from ecologists and biologists more frequently included factors impacting animals and the environment and are less focused on humans. Notably, no maps included factors that solely impact animals, indicating an important gap regarding aspects of the Bay of Plentzia that affect animals independently. During the search and selection of participants, reaching veterinarians or animal health experts in the area was challenging; the one participant with such expertise (FCM12) took a broad, holistic approach to health, placing limited focus on factors primarily affecting animals. This gap in animal health is reflected throughout the study, appearing in both the essential themes and the triangular diagram analysis. Maps clearly emphasise human-centred health and environmental intersections, but limited attention is given to factors affecting animal health; it is often addressed indirectly as a secondary consequence of factors initially related to humans or ecosystems.

Centrality

Besides the essential themes extracted from the storylines, network characteristics can also give insights into how the participants perceive the HSES of the Bay of Plentzia and the most relevant risks and threats in the area. Centrality reflects the contribution of a component in the overall network, and it is computed by combining its weighted incoming and outgoing connections. Higher centralities indicate higher influence of an individual component in the

cognitive maps (Kosko, 1986; Özesmi & Özesmi, 2004). Several of the components with the highest centralities refer to **Water quality** (HCM8, HCM9) and **Water pollution** (HCM17), and more specifically to **Emerging contaminants** (HCM3) and **Pollution from plastic waste** (HCM6).

In HCM7, elaborated by a participant from the enterprise that manages water sanitation in the area, the highest centrality belongs to the **Physicho-chemical treatment of water at the WWTP**. In the map of the economist (FCM14), the most central component is **Human health**. In the maps of health experts, the most central ones refer to physical health promotion, i.e. **SOAF** (FCM2), **Mental health** (HCM16), and the area's **Activity of the healthcare centre** (HCM15). In HCM12, the most central component is **Education for better knowledge on one's own health** to understand health from the integrated One Health perspective.

The presence of **Green and blue spaces** is the most important component in HCM1; in HCM5, it is **Contact with blue and green spaces**. Other components with high centralities are **Terrestrial biodiversity** (HCM4), **Microbiota health** (HCM13), **Acute gastrointestinal infections** (HCM10), and **Impacts in urban areas** (HCM11).

In-degree

High in-degree values indicate those components that are more influenced by other components (Özesmi & Özesmi, 2004). In many maps from medical experts and other diverse backgrounds, the component with the highest in-degree is related to human health (**Physical health** in HCM5, **Government initiatives to promote health** in HCM12, and **Human health** in HCM13 and HCM14). **Mental health** is the most influential component in HCM16, elaborated by a mental health expert. However, it is also in FCM1, where the author works at the tourism department of a local authority. Moreover, **Happiness** is the most affected component in a map elaborated by a medical microbiologist researcher, together with **Impacts in urban areas** (FCM11). **Physical health** appears as components with the highest indegrees in maps HCM2 and HCM5, both elaborated by agents focusing on this health domain. In HCM10, created by a biochemistry researcher, **Acute gastrointestinal infections** is the component with a higher in-degree. The most influential component for the human health expert interviewed in HCM15 is the **Activity of the healthcare centre**. In HCM12, from a veterinarian, the component with the highest in-degree is **Agricultural diversity** (HCM12). Biodiversity is also a component usually affected by the network, especially in ecologist's maps, both **Terrestrial biodiversity** (HCM4) and **Aquatic biodiversity** (HCM3, HCM7). Finally, the presence of **Pollution from plastic waste** (HCM6) and **Microplastics** (HCM4), the **Water quality** (HCM7, HCM8, HCM9) and the **Physicho-chemical treatment of water at the WWTP** (HCM7) are also components with high in-degrees.

Out-degree

Greater out-degrees reflect components with higher influence in the network (Özesmi & Özesmi, 2004). For many of the participants, components related to **Green and blue spaces** have the highest out-degree; it is merely their presence (HCM1), the contact of humans with them (HCM5) and the **Emotional connection with nature** (HCM16). The **Hikes** organised in the mountains surrounding the Bay are also seen as an influencing factor by human physical health experts, as well as the presence of the **SOAF** (HCM2). In other maps, many of the components with high out-degree refer to environmental conditions, especially climate-related. In HCM7, which talks about the WWTP, the most influential component is **Sunny and warm weather**, which increases sea temperature, attracts people into the Bay, and complicates the overall water treatment process (HCM7).

An **Increased sea temperature** also has the highest out-degree in HCM11 because of its effects on the local environment and aquatic animals' health. Similarly, the component **Climate change**

in HCM13 has the highest out-degree due to its impacts on the environment and all living beings. **Rainfall** also appears to be an important component in HCM9, principally due to its relation with wastewater treatment process and the increased contamination in the area. Another source of pollution, also with the highest out-degree in one of the maps (HCM4), is the **Livestock farming** of the area, not only for its negative impacts (manure production, effect on terrestrial biodiversity, soil compaction…), but also for its implication in the conservation of species of interest. In HCM10, the most influential components are **Microplastics** and **Coliform bacteria** for their impacts on environmental pollution and diseases in living beings. In HCM8, it is **Water quality** for their impacts on human, animal, vegetal, microbial, and environment health (HCM8).

Socio-economic characteristics, especially those related to politics and administration, are some of the highest out-degree components in maps elaborated by researchers from diverse backgrounds and local associations. In HCM3, **Coordination and communication from and between administrations** are seen to impact many components, such as "Sustainable tourism" practices, "Accidental spill pollution", "Illegal fishing in river and estuary", and the overall "Anthropic impact" on the area. The **Implementation of environmental policies** (HCM6), the **Provision of public services for Plentzia Bay** (HCM14) and the **Institutional and budgetary resources available for Plentzia Bay** (HCM17) are also components with high out-degrees. In HCM15, elaborated by one human health expert, the most influential component of the network is **Precarious working conditions**. Finally, for Participant 12, the component with the highest centrality is **Education for better knowledge on one's own health** (HCM12).

In summary, human health is one of the main concerns of local experts, including its physical and mental dimensions and the resources allocated to ensure quality healthcare. The environmental conditions of the Bay of Plentzia also play a major role in the HSES. Although not all participants acknowledge the health of the environment on its own, they recognise its vital link to the life of other organisms, including humans. Water quality, weather and climatology, blue and green spaces, and microbiological quality are essential factors. The area is characterised by the close interaction between urban and natural spaces, which is also acknowledged by the participants, as well as the extreme seasonal population dynamics experienced throughout the year and the impact of economic activities. Higher out-degrees are more closely associated with proposed actions. The experts interviewed highlighted several priorities: improving the health care system, enhancing of environmental education and awareness, promoting sustainable urban and infrastructure development, adopting environmental policies and regulations, and encouraging practices for monitoring and research.

Conclusions

The cognitive maps generated through this research reveal intricate networks that transcend single-disciplinary perspectives, highlighting the interconnectedness of factors across multiple disciplines. These integrated networks emphasise the importance of holistic approaches and broad multidisciplinary participation to address health challenges effectively (Hitziger et al., 2021). By employing Fuzzy Cognitive Maps (FCMs), we successfully incorporated diverse, situated knowledge drawn from the personal and professional experiences of individuals directly interacting with the socio-ecological system (SES) of Plentzia Bay. Factors with the highest centrality in the network are primarily associated with environmental aspects such as green and blue spaces, microbiome health, biodiversity, and pollution. Additionally, water quality and

management, along with healthcare-related factors such as gastrointestinal infections, mental health, and education for health promotion, are central to the network. Components with the highest in-degree, indicating they are most influenced by other elements in the network, include biodiversity, pollution from plastic sources, and water quality. Health-related factors, such as physical and mental health, happiness, and gastrointestinal infections, are also highly influenced within the network. On the other hand, components with the highest out-degree, representing the strongest influence over the network, are largely environmental. These include the presence of green spaces, meteorological characteristics, and climate change. Other influential factors include water quality, microplastics, and coliform bacteria. In terms of socioeconomic factors, elements such as working conditions, livestock farming, inter-administrative coordination, the implementation of environmental policies, education for health promotion, and the availability of institutional and budgetary resources demonstrate strong influence over the network. Lastly, components such as an emotional connection with nature and recreational activities like hiking also play a crucial role in shaping HSES of the Bay.

The findings, however, reflect the perspectives of a specific group of participants, primarily from academic and research backgrounds, with limited representation from local government institutions, community collectives, or professionals specialising in animal health. This participant selection, shaped by the non-open nature of the process, inevitably influenced the results. While this approach provided a focused understanding, it may have amplified certain voices while side-lining others, potentially reinforcing existing power dynamics. Thus, our findings represent a partial view of the reality in the SES of Plentzia Bay.

Many of the proposed actions relate to systemic changes beyond the immediate reach of individuals, often leaving them feeling disempowered. However, some actions focus directly on actors' behaviour, such as reducing waste and shifting leisure activities to more sustainable models, which are tangible and actionable at the individual level. Despite these limitations, the FCMs offer a valuable first approximation of the factors shaping HSES of Plentzia Bay from a primarily environmental and human-centric perspective. It provides a science-based foundation for local interpretations of health-related challenges. Future steps to strengthen this research include expanding the participant base to encompass a wider diversity of knowledge systems and involving additional agents, as suggested by Chambers et al. (2021) and Norström et al. (2020). Incorporating these varied perspectives would enhance the depth and inclusivity of the analysis and promote the development of innovative pathways for action, particularly by involving specialised experts in underrepresented areas.

Ultimately, this exercise contributes to producing new knowledge and lays the groundwork for more integrated forms of understanding, relating, and acting in future initiatives, such as developing a One Health Living Lab. These integrated maps represent an initial step towards fostering collaborative and transformative approaches to address the interconnected health challenges in Plentzia Bay.

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