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Food for Thought

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Expanding the scope and roles of social sciences and humanities to support integrated ecosystem assessments and ecosystem-based management

Jamie C. Tam [1,*], Courtenay E. Parlee [1], Jill Campbell-Miller [1], Manuel Bellanger [2], Jacob Bentley [3], Vahab Pourfaraj [1], Evan J. Andrews [4], Sondra L. Eger [1], Adam M. Cook [1], and Gabrielle Beaulieu [5]

[1]Bedford Institute of Oceanography, Fisheries and Oceans Canada, Maritimes Region, 1 Challenger Dr, Dartmouth, NS, B2Y 4A2, Canada
[2]Ifremer, UMR 6308 Amure Rue Dumont d'Urville, 29 280 Plouzané, France
[3]Natural England, Nobel House, 17 Smith Square, London SW1P 3JR , UK
[4]Memorial University of Newfoundland, St. John's, Newfoundland and Labrador, A1C 5S7, Canada
[5]Parks Canada Agency, 1869 Upper Water St. Halifax, NS, B3J 1S9, Canada

* *Corresponding author: tel:+01 902 426 4880; e-mail: jamie.tam@dfo-mpo.gc.ca*
This is a contribution to the article series, "Rising tides – voices from the new generation of marine scientists looking at the horizon 2050". This collection of articles was jointly developed by ICES Strategic Initiative on Integration of Early Career Scientists (SIIECS) and ICES Journal of Marine Science. The collection is dedicated to and written by early career scientists.

Understanding social-ecological systems (SESs) is an important part of ecosystem-based management (EBM). One of the main decision support frameworks to develop scientific advice for EBM is integrated ecosystem assessments (IEAs). Human dimensions in SESs are primarily captured through indicators derived from three social sciences: economics, anthropology, and sociology. The breadth of social sciences and humanities (SSH) research is much greater than those three fields, but they are generally underused in natural science-based decision support processes such as IEAs. Greater contributions of SSHs can enhance IEAs through various direct (e.g. to develop indicators) and indirect ways (e.g. to establish and maintain ethical practices). We examine a wider range of SSH disciplines and conclude that scientific advice processes that inform EBM can benefit from broader integration of SSH theories and methods through themes of contextualizing, facilitating, communicating, evaluating, and anticipating. We see this an opportunity to both widen the vocabulary used to describe social scientists and those who work in humanities in IEAs, and apply the underlying worldviews used to conduct SSH research to fundamentally enhance the IEA process and to further progress in EBM.

Keywords: ecosystem based management, epistemological worldviews, human dimensions, integrated ecosystem assessments, social sciences and humanities.

Introduction

Considering the human dimensions of social-ecological systems (SESs) has been an important part of developing global ecosystem-based management (EBM) frameworks, analytical tools, and implementation plans for ocean management (Folke, 2006; Ostrom, 2009; Link *et al.*, 2017; Long *et al.*, 2017; Tam *et al.*, 2019; Bundy *et al.*, 2021; Marshak and Link, 2021; Kasperski *et al.*, 2021a). Human dimensions refer to a way to characterize the roles humans play in shaping and responding to change. Further, they focus on categorizing human interactions with the environment, such as concepts to address social, cultural, economic, and institutional relationships, experiences, and structures, related to the marine environment (Charles and Wilson, 2009). However, human dimensions have not been fully integrated through the vast array of social science and humanities (SSH) theories and methods in decision-making processes that support EBM.

Overarchingly, EBM is recognized as an adaptive, flexible, and holistic environmental management approach that accounts for the full array of interactions within an SES. EBM accounts for SES complexity, cumulative impacts, indirect effects, emergent properties, ecosystem-level reference points, and multiple human uses and values (McLeod *et al.*, 2005; Link and Browman, 2014; Leslie *et al.*, 2015; Link *et al.*, 2015; Long *et al.*, 2015; Tam *et al.*, 2017a; Stephenson *et al.*, 2021). EBM strategies should be both robust and adaptable to account for multiple levels of management decisions and address objectives from multiple ocean uses (Figure 1). EBM also necessitates the principles of good governance that recognizes coordination through which individuals and institutions manage common affairs, and where conflicting or diverse interests may be accommodated in an effective and efficient manner for the common good of society (Yu, 2018; Stephenson *et al.*, 2019; Steffek and Wegmann, 2021; Villanueva *et al.*, 2022).

Although there are a multitude of decision-support frameworks developed over the last few decades, the most widespread decision framework currently being used to support EBM is integrated ecosystem assessment (IEA) (Holling, 1978; Walters, 1986; Gregory and Keeney, 2002; Atkins *et al.*, 2011; Kelble *et al.*, 2013; Fath *et al.*, 2015; Hammond *et al.*, 2015; Patrício *et al.*, 2016). IEAs consider the integration of human dimensions in the form of social-cultural and economic indicators (e.g. community well-being, job satisfaction, and distribution of benefits), developed through SSH research,

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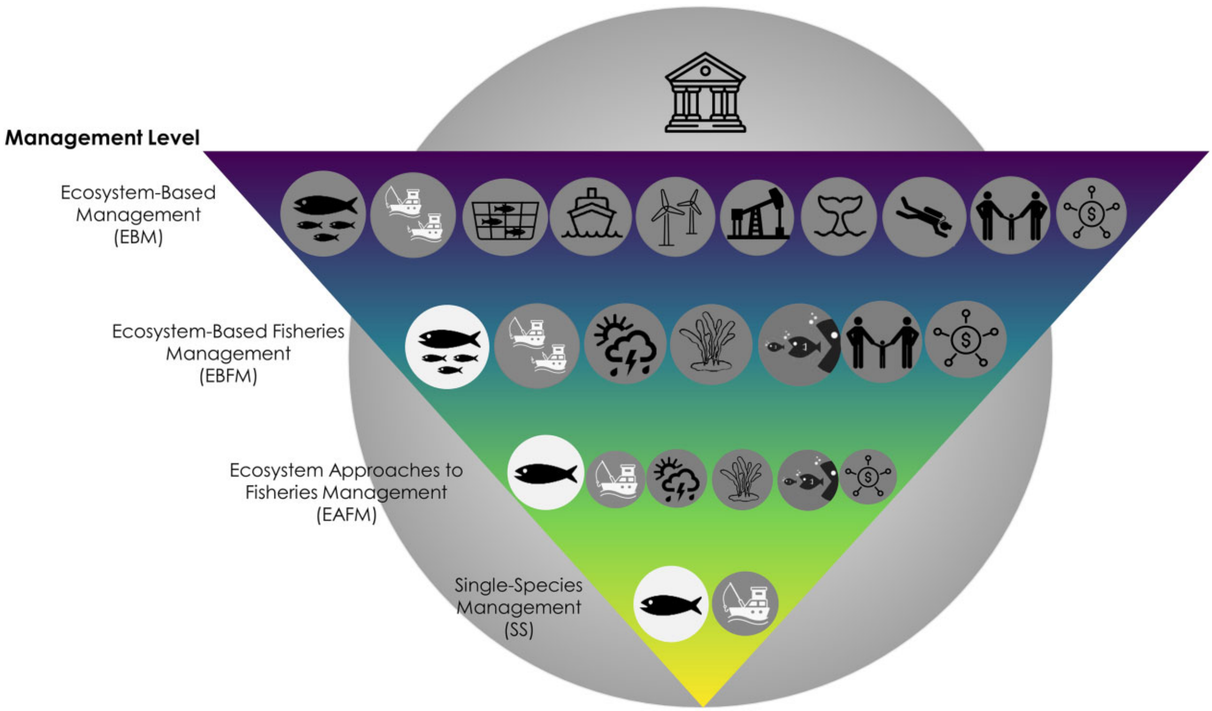

Figure 1. Varying management levels and potential considerations along the spectrum of EBM (triangle), whereby all management levels are guided by good governance (large grey circle), with varying management advice focus (white circles), and potential interacting components (small grey circles). Single species (SS) management incorporates biological information regarding the focal species or stock alongside fisheries information. Ecosystem approaches to fisheries management incorporate a wider breadth of information that could include any social-ecological information into SS or stock advice. Ecosystem-based fisheries management incorporates any social-ecological information into a multi-species and multi-stock advice process. EBM involves multi-sector management whereby marine ecosystems and fisheries are considered equal among multiple ocean uses (Hilborn and Walters, 1992; Walters *et al.*, 2005; Day *et al.*, 2008; Muffley *et al.*, 2021; Link and Marshak, 2022).

and are an important part of developing SES models to fully assess ecosystem status and risks (ICES, 2020a). It is important to note that IEAs are not formally used for assessments or decision-making in many countries. Even within the International Council for the Exploration of the Sea (ICES), where IEAs are included as a science priority and supported by IEA working groups, there is significant variation in the degree to which the full IEA framework is applied (Clay *et al.*, 2023). Despite this, the scientific advice provided through the partial or full development of IEAs has contributed significantly to furthering the operationalization of EBM globally (Dickey-Collas, 2014; ICES, 2020b; Monaco *et al.*, 2021).

The IEA framework

The IEA framework is a decision-support framework that outlines a series of steps to organize information derived from SESs to provide effective, integrative science support for EBM (Figure 2). The framework provides guidance towards organizing information and analyses to approach issue-driven objectives, with the inherent flexibility and adaptability required to address diverse multi-sectoral EBM issues (Levin *et al.*, , 2014; Samhouri *et al.*, 2014). Rather than focusing on tools (e.g. specific analyses) or products (e.g. deliverables or reports) of EBM, the IEA framework is process-oriented and is meant to be iterative and ongoing. Harvey *et al.* (2021) emphasize the importance of understanding the inseparable interrelation between the IEA tools, the IEA products, and the IEA process and the necessity for all three components to work synergistically to successfully implement EBM. IEA products are tailored to the end-user's needs, but the new information and tools gained from that process are then applied to subsequent iterations of the product.

The IEA framework is a logically and conceptually straightforward process for answering EBM questions, yet IEAs remain daunting and complex (Dickey-Collas, 2014). Without formal policy and financial support, which would allow practitioners to build capacity and develop a successful EBM programme implementing the IEA framework, it can be seen as an insurmountable goal for regional, national, or international groups. However, there have been many examples of efforts from a number of different countries and transboundary groups that have approached marine management issues in ways that align with at least part of the IEA framework (DePiper *et al.*, 2017; Bentley *et al.*, 2021; Howell *et al.*, 2021; PCA, 2022; ICES, 2023). This is a testament to how a flexible and adaptive framework can be used to support good decision-making whether it be for explicit EBM purposes or to address more specific management questions. While IEAs are envisioned as the "gold standard" for EBM implementation, successfully adding to or completing parts of the process should be seen as an encouraging step towards EBM.

SSH disciplines

Broadly, SSH disciplines focus on the systematic study of, and research involving, humans and social phenomena. The social sciences refer to studies concerned with different aspects of the life of an individual within a group or society as well as social interactions between groups and their environments, whereas the humanities refer to studies on distinctive elements of human culture (Charles and Wilson, 2009; ICES, 2022a). The

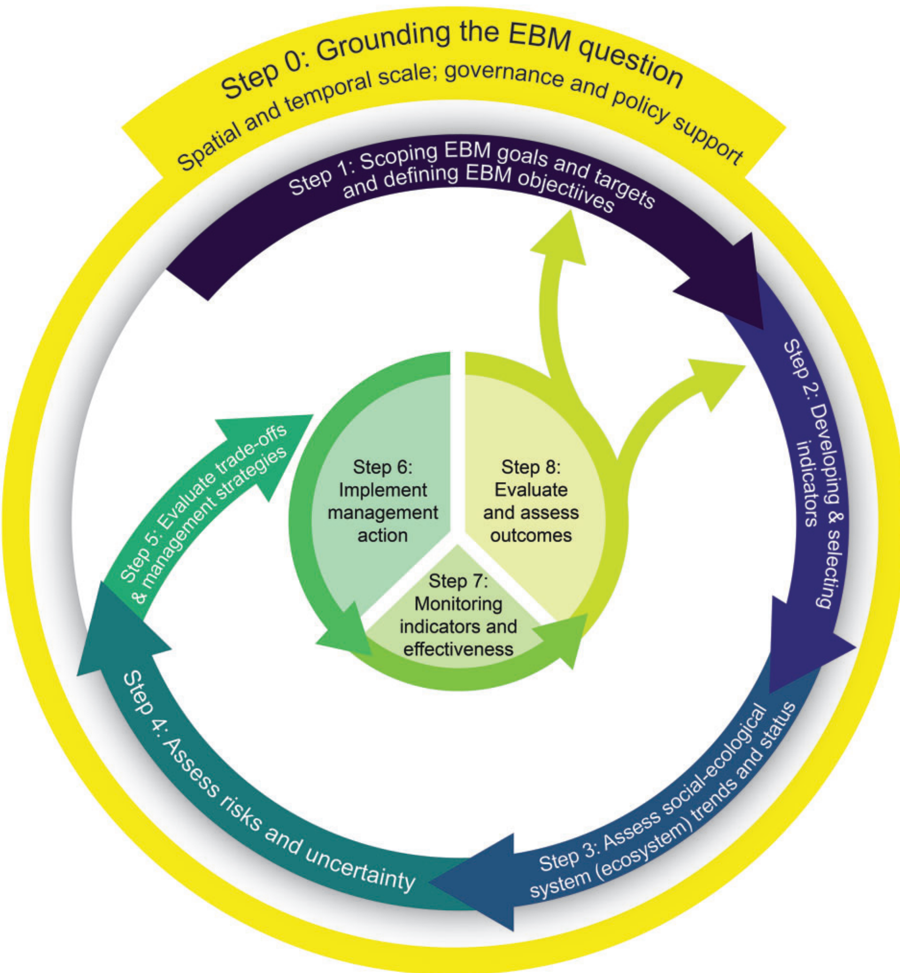

Figure 2. Enhanced IEA framework modified from Levin *et al.* (2009) and Samhouri *et al.* (2014) that accounts for SSH contributions.

SSHs rely on a range of epistemologies (theories of knowledge or worldviews) to guide and analyse their research design and select appropriate methods. SSHs follow primarily positivist, interpretivist, and constructivist worldviews. **Positivism** is mostly associated with natural sciences, though it is sometimes used in the social sciences. It posits that only verifiable claims based directly on experience can be considered as legitimate scientific knowledge (as opposed to beliefs). Based on this theory, researchers are objective seekers of truth; there is one identifiable reality; methods to discover knowledge are replicable and verifiable through logically deduced hypotheses, key concepts, and variables (Patton, 2002; Meissner, 2016). **Interpretivism** posits that the researcher and reality are inseparable, realities are social, and experience-based and there are multiple realities dependent on the interpretation of individuals (Lincoln and Lynham, 2011). **Constructivism** recognizes that researchers have prior knowledge and experiences, which are often determined by their social and cultural environment. Constructivists believe that each individual's way of making sense of the world is created through cultural and social influences, and that they are valid and worthy of respect (Patton, 2002). Interpretivists are interested in how realities are individually experienced, while constructivists are interested in how those realities are constructed and used to make knowledge. These epistemologies differ in the way that they access knowledge and truth, the degree to which the world can be sensed and described by people, and how to assess propositions (Patton, 2002; Schnegg, 2015). In general, SSHs, particularly the social sciences, were most profoundly shaped by positivism around the early 1940s and have since moved towards more interpretivist and constructivist epistemologies (Backhouse and Fontaine, 2010).

SSH gaps in IEAs

The integration of human dimensions has continually been seen as a gap in IEA processes, primarily due to the fact that natural scientists greatly outnumber social scientists and those who study humanities in EBM programmes, and thus have limited time and capacity to make progress. Siloed research programmes often make the collaboration to achieve multidisciplinary (combining multiple disciplines to answer a research problem) or transdisciplinary (using multiple disciplines and related groups to co-develop research) between SSH scholars and natural scientists difficult or seemingly impossible (Bavinck and Verrips, 2020; Kraan and Linke, 2020; Szymkowiak, 2021; Clay *et al.*, 2023). However, the landscape of IEAs is changing rapidly, and more emphasis has been placed on bolstering SSH contributions and input into IEAs (deReynier *et al.*, 2010; Samhouri *et al.*, 2014; Harvey *et al.*, 2021; Spooner *et al.*, 2021; ICES, 2021a, 2022a; Link and Marshak, 2022). Thus, as the integration of SSHs into natural science-based processes becomes more prominent, the lessons learned from such multidisciplinary and transdisciplinary EBM projects make IEAs more robust. It can allow research to tie the science advice process back to human communities (Belgrano and Villasante, 2021).

Currently, in global IEA processes, formal input from the social sciences (where examples exist) comes primarily from economists, anthropologists, and sociologists to develop operational social-cultural and economic indicators (Pollnac *et al*., 2015; Colburn *et al*., 2016; DePiper *et al*., 2017; ICES, 2020a). However, there is a vast array of SSH disciplines that could help in decision-making processes directly (e.g. to facilitate the selection process of indicators for operational use) or indirectly (e.g. building trust and gaining consensus). Bennett *et al*. (2017) provide a comprehensive review of conservation social sciences and how such specialized disciplines can contribute descriptive, diagnostic, disruptive, reflexive, generative, innovative, and instrumental benefits towards reaching conservation and sustainability goals. In the context of fisheries, Szymkowiak (2021) suggests four key human dimensions for inclusion in ecosystem assessments: multifaceted nature of human well-being, heterogeneity in human well-being derived from fisheries, adaptive behaviour, and cumulative effects. While such descriptions and contributions for achieving overarching environmental sustainability goals are extremely valuable, the application of SSH to specific scientific advice frameworks and processes remains ambiguous.

There is an opportunity to widen the vocabulary used to describe SSH in EBM and to explore how a variety of SSH disciplines can be applied beyond their current use in the IEA process to better integrate and to increase the use of SSH methods in EBM. While the IEA framework relies on positivism as the main epistemological worldview, we attempt to explore how interpretivist and constructivist theories can also be applied to IEAs in a practical and pragmatic way through the various SSH disciplines. This paper outlines a wider range of SSH disciplines and methods, drawing on workshop discussion and research on extant literature to show how SSHs can be better integrated into all steps of the IEAs with the overall goal of strengthening the incorporation of human dimensions in EBM.

SSH contributions to steps in the IEA process

The authorship is comprised of early career experts from ecology, anthropology, sociology, history, biology, and economics with backgrounds in government, academia, and as members of boundary organizations such as the Ocean Frontiers Institute, and Canadian Fisheries Research Network. Two authors are chairs of ICES Working Groups within the IEA Steering Group, all have participated in either multidisciplinary or transboundary projects, where gaps in SSH roles and methods have been acknowledged (see Supplementary S1 for more details).

Themes from disciplines were connected to specific IEA questions through review of current and relevant literature (both academic and grey literature) and by leveraging the multidisciplinary expertise among the author team during monthly workshop sessions (total 10) parsing the connections in extensive discussions until consensus was reached (see Supplementary S1 for more details). As each author had expertise from a range of disciplinary backgrounds, they were able to identify applicable literature from their own fields to inform the arguments. Where literature gaps were identified, the authors undertook searches on specific topics (e.g. methodological approaches from various fields) to fill in those gaps.Themes were defined as recurring ideas derived from observations by the authors. The identified themes were connected to general SSH disciplines (Table 1) and further SSH research methods with examples discussed at each IEA step. It is noted that disciplines do not exclusively speak to a particular SSH theme, but the themes were derived from the dominant skillset based on research methods and outputs (Supplementary S2). There were five common themes across SSH disciplines that describe how the SSH disciplines could benefit the IEA framework and EBM:

- ***Contextualizing***: To consider and/or provide information about a situation, time period, or place in which an event, activity, action, or interaction occurs.
- ***Facilitating***: To enable processes, procedures, or mechanisms. This could include, but is not limited to, engagement, conflict resolution, or selection processes.
- ***Evaluating***: Determining or assessing the amount, number, or value of something. This can include estimating, appraising, valuating, and rating with respect to worth or significance.
- ***Communicating***: A process by which information is exchanged between individuals through a common system of language, symbols, signs, or behaviour. This includes different forms of communication products (e.g. art, music), but also how communication happens (e.g. language, rhetoric).
- ***Anticipating***: Planning or preparing a response to something before it happens. This is a core concept within good governance and promotes a full understanding of trade-offs in decision-making.

There were 26 disciplines identified from a review of current and relevant literature on extant SSH methods that broadly encompassed the SSHs (Table 1). It is noted that there are a vast number of branches (sub-disciplines) that were not exhaustively examined. For example, clinical psychology (the field of practice that deals with human functioning in promoting physical, mental, and social well-being) and social psychology (the study of personality and social interactions) are distinct branches that fall under the psychology discipline. Considering the extensiveness of SSH disciplines, there are likely more useful methodologies for supporting IEAs and EBM than are currently used or can be meaningfully documented here.

The identified SSH themes and disciplines (Table 1) were then linked to steps in the IEA process where the authors qualified the dominant themes, through consensus achieved during workshop discussions (Table 2). It was noted when more than one SSH theme would be useful. The relative importance of the themes to each IEA step was then ranked based on the number of instances where the discipline associated with each theme could be used to address an IEA step or related question (Figure 3). This provided insight into priorities for specific SSH disciplines at each IEA step.

Step 0. Grounding the EBM question

In reviewing the IEA framework and existing SSH contributions, we recognized that there was a missing overarching step in the framework. Step 0 or Grounding involves a pre-implementation stage in management, governance, or science

Table 1. Social sciences (shaded white) and humanities (shaded grey) disciplines and associated dominant themes in the context of IEA and EBM.

Themes	Discipline	Traditional definition
Contextualizing	Archaeology	Study of human activity through the recovery and analysis of material culture. This consists of recording artefacts, architecture, and cultural landscapes
Contextualizing	Classics	Study of the ancient world, typically Greek or Roman. Can be focused on ancient cultures, economies, medicines, and governance
Contextualizing	Demography	Studies the dimensions and dynamics of populations, including whole societies or groups defined by criteria such as education, nationality, religion, and ethnicity
Contextualizing	Ethnology	Study of nations and peoples that compares and analyses the characteristics of different peoples and their relationships between them
Contextualizing	Gender studies	Study of gender identity and gendered representations, can include women's studies, men's studies, and queer studies, etc.
Contextualizing	Geography	Study of the Earth, its features, and phenomena that take place on it. Human geography focuses on the built environment and how humans view, create, manage, and influence space. Human geography can also study intangible objects, including discourses, identities, and places of inscription
Contextualizing	History	Study and documentation of human activity, with many branches including environmental history, political history, etc.
Contextualizing	Philosophy	Study of general and fundamental questions about existence, reason, knowledge, values, mind, and language
Contextualizing	Religious studies	Research in religious beliefs, behaviours, and institutions. Can focus on systematic, historical, and cross-cultural perspectives
Facilitating	Anthropology	Study of humanity with focus on human behaviour, human biology, human cultures, human societies, and human linguistics
Facilitating	Management sciences	Study of solving complex problems and making strategic decisions, solving organizational and management problems, or understanding an organization better as it pertains to institutions, corporations, governments, or other organizational entities
Facilitating	Psychology	Study of mind and behaviour in humans, involving perception, cognition, attention, emotion, intelligence, subjective experiences, motivation, and personality. Social psychology focuses on thoughts, feelings, and behaviours influenced by social norms
Facilitating	Public policy and administration	Study of public policies and programmes by government agencies and officials at various levels of government, focused on efficient and effective delivery of public services to citizens
Facilitating	Sociology	Study and application of skills to understand social behaviour and interactions, develop relationships, and address conflicts
Communicating	Communication studies	Study of the processes of human communication and behaviour, patterns of communication in interpersonal relationships, social interactions, and communication in different cultures
Communicating	Education	Study of the application of pedagogy, a body of theoretical and applied research relating to teaching and learning
Communicating	Linguistics	Study of human language, entailing cognitive, social, environmental, biological, and structural components of language
Communicating	Literature	Study of written work as history or art, including prose, drama, and poetry. This study also includes recording, preserving, and transmitting knowledge and entertainment through literature
Communicating	Music and performing arts	Study or development of music or performance, including social and cultural aspects and theatrical processes
Communicating	Visual arts	Study or development of art forms such as painting, printmaking, sculpture, photography, filmmaking, design, and architecture
Evaluating	Accounting	Study and profession of measuring, processing, and communicating financial and non-financial information about economic entities
Evaluating	Economics	Study of the production, distribution, and consumption of goods and services, with focus on the behaviour and interactions of economic agents and how economies work
Evaluating	Law	Study of the rules that are enforceable by social or government institutions to regulate behaviour
Anticipating	Behavioural studies	Study of human behaviour as it relates to the impacts on society as a whole
Anticipating	Futures studies	Study of social, technological, and environmental trends for the purpose of exploring probable and preferable futures, including the worldviews and myths that underlie how people and societies will live and work in the future
Anticipating	Political science or policy studies	Study of politics, dealing with systems of governance or power, and the analysis of political activities, political institutions, political thought, behaviour, and theory, alongside associated constitutions, laws, and policies

Themes were determined through workshop discussions and consensus by the authors utilizing background research of traditional definitions and common research methods from each discipline (see also Supplementary S2).

Table 2. Steps of the IEA framework, associated to themes derived from Table 1, specific SSH disciplines or branches, and skillset to address related questions.

	Questions	Theme	Potential SSH discipline or branch	Desired skills
Step 0. Grounding the EBM question	*What is the relevant spatial scale time frame, and historical context with regards to the EBM objectives?*	Contextualizing	Environmental or Conservation History, Fisheries History, Marine Anthropology, Religious Studies, and Indigenous Studies	Familiarity with conducting oral histories of the location or region (e.g. interviews). Experience with critical analysis of policy documents. Understanding of diverse worldviews and how they are applied to EBM questions.
	What are the current and historical governance or policy barriers and opportunities for achieving the EBM objectives?	Contextualizing	Political/Policy Science, Political History, Environmental Anthropology, Environmental, or Conservation Law	Understanding of the local/regional governance systems and how policies impact people, analyse how people react to policies in the region. Experience reconciling conflicting policies. Familiarity with ethical standards for research on human beings.
Step 1. Scoping EBM goals and targets and defining EBM objectives	*Who has the regulatory decision-making power, and what are the ongoing top-down vs. bottom-up processes to achieve the EBM objective?*	Facilitating	Political science	Understanding power dynamics and how policies and legislation are regulated. Experience identifying bottom-up initiatives in the context of EBM and if they have been in conflict with top-down policies.
	Who are the rightsholders, stakeholders, and duty-bearers linked to focal components of the EBM targets and goals, and how/when should they be engaged? *What is the current and future capacity for relevant parties to participate in the research?*	Facilitating and contextualizing	Cultural or Marine Anthropology, Sociology with expertise in Conflict Theory, Political or Environmental History, and Ethnography	Experience with stakeholder analysis (e.g. stakeholder-mapping tools). Understand historical context of the region, nuances, past regulatory measures, and power dynamics.
	Have EBM questions been developed in a transparent way? *How can trust be built and maintained among all parties?*	Facilitating	Social Psychology and Human Geography	Understanding of various methods to engage with a variety of different rightsholders and stakeholders (e.g. visioning exercises). Experience as a communications liaison or building healthy communities of practice.
	Do all parties understand the EBM objectives or potential trade-offs?	Facilitating and communicating	Science Education, Communications, Visual Arts, Linguistics, Political Sciences, Governance, and Management	Expertise with conflict resolution. Knowledge and experience with various communication tools.
Step 2. Developing and selecting indicators	*Are these indicators qualitative or quantitative?* *What timescale of the data?*	Evaluating and contextualizing	Fisheries or Environmental Economics, Fisheries or Marine Anthropology, Environmental Sociology, Demography of Coastal Communities, and Human Geography	Expertise with spatial and temporal human community data in marine spaces. Knowledge of census and other survey data.
	What are the monitoring and research requirements for new indicators? *Are human ethics processes required?*	Evaluating and anticipating	Sociology, Economics, and Anthropology	Expertise working with alternative methods such as data mining to develop indicators. Experience with interpretive-based methods (e.g. semi-structured interviews, and survey development).

Table 2. Continued

	Questions	Theme	Potential SSH discipline or branch	Desired skills
	Are these indicators sufficient to answer questions in Step 1 within the context of Step 0? Do these indicators provide tactical or strategic information?	Evaluating	Fisheries or Conservation Law and Fisheries Policy	Understanding regional decision-making and familiarity with the process of resource management decisions.
	Does the suite of indicators resonate with end-users, rightsholders, and stakeholders? What is the ideal number of indicators to use?	Facilitating and anticipating	Psychology, Environmental Education, and Futures Studies	Expertise in selection methods (e.g. structured decision-making, alternative dispute resolution).
Step 3. Assess SES trends and status	*Which analysis should be used to assess the status and trends? Do rightsholders, stakeholders, and duty-bearers understand the research results?*	Evaluating and communicating	Environmental or Marine Economics, Maritime Law, and Anthropology	Familiarity with interpreting trends and status of indicators. Understanding of how to best communicate complex interactions to a diverse audience.
	What are the relevant benchmarks? Are reference limits linked to regulatory measures?	Evaluating	Marine or Policy Science and Economics	Understanding of management or policy regulations that are able to change due to surpassing a threshold or reference point limit.
Step 4. Assess risk and uncertainty	*What are the short-term and long-term risks posed by human activities and environmental pressures on the SES? Do rightsholders, stakeholders, and duty-bearers understand the risks presented?*	Evaluating, communicating, and facilitating	Marine of Fisheries Social Science, Ecological Economics, Communications, and Visual Arts	Understanding of cumulative risks and risks of indirect impacts of risk elements within an SES. Understanding of rightsholder or stakeholder perception of risk.
Step 5. Evaluate management strategies and trade-offs	*What type of model or analysis is appropriate for the selected indicators?*	Evaluating and facilitating	Marine Social Science and Ecological Economist	Familiarity with SES modelling, including network modelling or conceptual mapping and model selection. Experience facilitating a selection process.
	What management scenarios should be examined?	Evaluating and anticipating	Marine Social Science, Ecological Economics, and Marine Policy Science	Experience with scenario planning, linking scenarios to management adaptations. Understanding priorities and concerns of rightsholders and stakeholders.
	What are the tradeoffs? Which management scenario should be implemented?	Evaluating and communicating	Marine Anthropology, Communications, and Visual Arts	Experience with decision-making analyses and processes. Ability to mitigate conflicts within and between related groups.
Step 6. Implement management action	*What management action(s) were taken? How is information regarding IEAs transferred from science to policy?*	Communicating and facilitating	Marine Policy Science, Public Policy, and Information Management	Understanding the science-policy interface of the region. Familiarity with the institutional culture and workflow.
Step 7. Monitor SES indicators and management effectiveness	*What is the time interval between sampling periods? Who is responsible for collecting indicator data?*	Evaluating and facilitating	Anthropology, Sociology, and Behavioural Science	Familiarity in survey methods and how to implement long term surveys for tracking SES indicators.
	To whom do these data belong? Who has rights to use this data? How should the datait be used?	Evaluation, contextualizing, and anticipating	Data Regulations Law, Public Policy Science	Understanding of data ethics. Training in First Nations principles of Ownership, Control, Access, and Possession (OCAP®).

Table 2. Continued

	Questions	Theme	Potential SSH discipline or branch	Desired skills
Step 8. Evaluate and assess outcomes	*How are impacts evaluated? How often are they evaluated?*	Evaluating	Marine Social Science, Marine Policy Science, Ecological Accounting, or Economics	Familiarity with developing evaluation methods for process frameworks.
	What is the best pathway to influence the next IEA cycle? How is this evaluation communicated?	Anticipating and communicating	Policy Science, Futures Science, Visual Arts, and Performance Arts	Experience with governance/institutional culture to determine pathways for EBM success. Experience communicating evaluations to a variety of audiences.

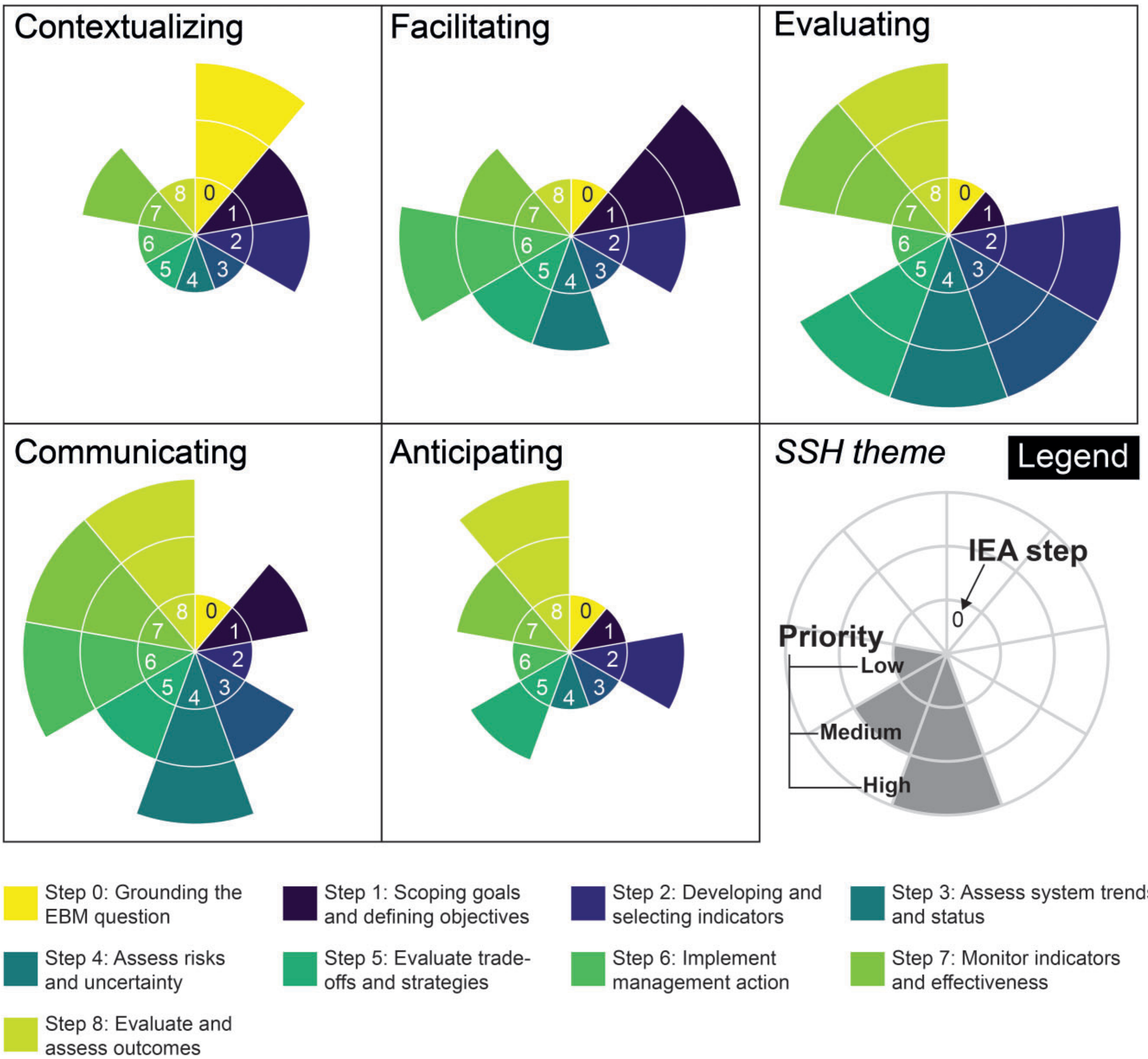

Figure 3. Contributions to each IEA step from SSH themes of Contextualizing, Facilitating, Evaluating, Communicating, and Anticipating. The ranking where each theme emerged in each step determined the level of priority (low, medium, and high) that should be applied to a particular theme for each step of the IEA framework.

practices to define the historical and regional context before a given programme is implemented. In the development of new EBM programmes, this requires a recognition and understanding of the spatial and temporal boundaries under which the management is undertaken. Large-scale ecoregions, such as large marine ecosystems (Tam *et al*., 2017a) or ecological production units (DePiper *et al*., 2017) are often used as the scale for EBM; however, other boundaries such as international/national borders (e.g. NAFO divisions; Koen-alonso *et al*., 2019) can be used to define the boundaries of a managed ecosystem. Some IEA products are required on an annual basis (NOAA-Fisheries, 2023a) and used alongside tactical scientific advice (e.g. recommendations for total allowable catch, F_{msy}), while other IEA products have a longer interval for strategic purposes (ICES, 2023).

The Step 0 process mainly involves *contextualizing* the EBM question once spatial and temporal boundaries are determined (Figure 3). Part of this contextualization could involve a review of or research on the history of the location or region. This would inform an understanding of the area's (inter)relationship with natural resources and prior relationships to decision-makers and duty-bearers that have the obligation to respect, protect, promote, and fulfil human rights (UN, 1948). The primary disciplines that could contribute to this step are history and anthropology, but in some cases, cultural contexts may be important (Vaughan *et al*., 2017). An understanding of the religious or spiritual values of beliefs common to the location or region can, through religious studies, for example, guide social norms around resource management (Cox *et al*., 2014; Hartberg *et al*., 2016). This process can: identify the connection and importance of people and communities to the natural resource or place (cultural attachment), pinpoint sources of distrust, reveal past and present power dynamics within communities as well as power dynamics between communities and decision-makers, identify attempted or implemented EBM approaches, and familiarity of user groups to these approaches (Davenport and Davenport, 2005; van Putten *et al*., 2018; Delozier and Burbach, 2021; Haapasaari and van Tatenhove, 2022). This creates the foundation for coproduction of EBM objectives (Figure 2; Step 1 of the IEA process) and the development of effective communities of practice that ensure transparency and environmental justice are included as part of good governance (Funtowicz and Ravetz, 1992; Zador *et al*., 2017; Campanale *et al*., 2021).

Another important aspect of Step 0 in an EBM process is to understand the nuances of governance, management, and policy support to implement EBM. Governance is "the mechanisms and processes by which power and decision-making are allocated among different actors", whereas management involves operational decisions about use patterns and incremental improvements to policies, regulations, and laws (Kearney *et al*., 2007). The lack of consideration of governance has hindered the operationalization of holistic approaches to environmental management, such as EBM, including inappropriate governance arrangements (Eger *et al*., 2021). Understanding past (e.g. historical expertise), present (e.g. public policy expertise), and plausible future (e.g. behavioural, futures, or political science expertise) legislative and governance processes shape the EBM questions that can be asked. It can also indicate which IEA tools and products would work best for implementing EBM at the necessary spatial and temporal scales. In the development Fisheries and Oceans Canada (DFO) Maritimes EBM framework, EBM objectives (balanced across pillars of ecological, social-cultural, economic, and governance sustainability) were drawn from national and regional policy and regulation such as the Fisheries Act, Oceans Act, and Species At Risk Act (Stephenson *et al*., 2018; Daly *et al*., 2020; Bundy *et al*., 2021). Harvey *et al*. (2021) noted that in the US, the pathway to EBM involves leaning on the Magnuson-Stevens Act, the Marine Mammal Act, and various executive orders (e.g. National Ocean Policy) to draw objectives for the IEA framework. The EU implemented the Marine Strategy Framework Directive, which aimed to achieve "good environmental status" (Palialexis *et al*., 2014). In the case of new or amended marine management programmes there are opportunities to embed aspects of EBM within policy and guidance frameworks. Parks Canada has developed its own National Marine Conservation Area Policy with legislative requirements to manage these protected areas in a holistic way with considerations for human well-being, inclusive and collaborative governance, protecting ecosystems, and climate change mitigation and adaptation (PCA, 2022).

While components of Step 0 may be alluded to in the IEA literature as part of Step 1 (Scoping; Levin *et al*., 2009; Samhouri *et al*., 2014), we assert that Step 0 should be its own step (Figure 2), with emphasis on SSH theory, skills, and input that is necessary to form the basis for all the subsequent IEA steps (Figure 2). Reflecting upon Step 0 during any step in the IEA framework should be a common practice.

Step 1. Scoping EBM goals and targets and defining EBM objectives

The original intent of Step 1 in the IEA framework was to understand drivers and specific pressures on ecosystems related to the EBM problem or question (Levin *et al*.,). Related groups associated with those drivers or pressures would then be engaged to provide context to or contribute to research (Samhouri *et al*., 2014). Without Step 0, identifying the problems and developing the questions prior to establishing the context could risk disengagement and distrust as related groups or end-users may not feel that their objectives are reflected in the scoping step. Gunton *et al*. (2010) and Colvin *et al*. (2016) found that stakeholder analysis and socioeconomic scans (commonly used in the discipline of geography) of the communities can help to identify who needs to be at the table and why, and how they might be impacted by management actions. It can allow project teams to explore multiple approaches, to identify related groups for participation in environmental management, and to recommend going beyond the "usual suspects." They concluded that using a variety of methodologies for engaging related groups could help to avoid "blind spots" and ultimately improve the science advice by incorporating a greater number of perspectives to the decision-making process.

The SSHs can also provide further nuance to the types of groups that could be involved in answering EBM questions. This includes key distinctions between related groups or end-users and how their engagement and input should be prioritized. In the original context of the IEA framework, such related groups are referred to as stakeholders. Here, we define stakeholders as individuals or groups that derive benefits from the use of resources, have a vested interest, or hold legal or *de facto* rights to manage or make decisions (e.g. government authorities, industry groups, and NGOs). However, it is important to understand key distinctions among these groups or end-users. Rightsholders, who are individuals or social groups that have particular rights and entitlements. They differ from stakeholders in that affirmative actions are needed to respect, protect, and fulfil the rights of such groups and may require separate engagement processes or co-production pathways (e.g. Indigenous groups and vulnerable minority groups). For example, the rights of Indigenous Peoples to consultation must also be considered when taking actions or making decisions (e.g. duty to consult, free, prior, and informed consent) (UN, 2007; FAO, 2016). Parks Canada (PCA, 2023) is developing an Indigenous Stewardship Framework (co-produced with Indigenous partners and members of the public) to manage protected areas in ways that support the priorities of Indigenous peoples and to engage in a two-eyed seeing approach, "to see from one eye with the strengths of Indigenous ways of knowing, and to see from the other eye with the strengths of Western ways of knowing, and to use both of these eyes together" (Marshall *et al*., 2015; Kutz and Tomaselli, 2019; Reid *et al*., 2021). Those with expertise in Indigenous knowledge, marine policy, or management may have a better understanding of how best to engage with rightsholders and stakeholders within the context of current or historical governance systems for achieving EBM goals.

Once relevant rightsholders and stakeholders have been identified and engaged, EBM goals and targets should be scoped, and meaningful objectives should be developed. It is important to note the difference between a typical natural science-driven targets (e.g. regulatory target, terms of reference, and set of principles) and objectives. Gregory *et al.* (2012) note that the things that matter most (objectives) when making a choice are closely linked to a community's cultural values or an individual's perceptions and, in many cases, are qualitative in nature. For example, can and should a plan assess the impacts of a dam on the Indigenous spiritual value of interconnected waterways? If so, how? Other major weaknesses in selecting targets and objectives are linguistic ambiguity leading to disagreements regarding the intent of objectives and selecting targets that cannot be connected back to policy or regulatory measures (Domínguez-tejo and Metternicht, 2018). Documenting what matters to rightsholders, stakeholders, and decision-makers and developing a complete and clear suite of objectives linked to targets and policy is a time-consuming and important step that would benefit from skills derived from many SSH disciplines.

Thus, the focus of SSH inputs into Step 1 of the IEA framework is *facilitation* (Table 2) to ensure that power imbalances and distrust are recognized, to engage with rightsholders and stakeholders in an appropriate and ethical manner, to enable consensus regarding objectives, and to clearly articulate and define those objectives to related groups. Considering the wider inputs of such contributions, both *contextualizing* and *communicating* also emerged as important themes (Figure 3). Parlee *et al.* (2023) as part of a transdisciplinary team with fisheries anthropology, sociology, and history expertise, used a phased participatory approach to engage with lobster harvesters and Indigenous groups that allowed the researchers to reflect on problems with previous studies surrounding the fishery. This led to a research plan to explore objectives of the fishery for the region that explicitly addressed potential ethical concerns that might arise. Science education, deliberation, communication, and different forms of art are also useful avenues for developing consensus regarding objectives (Bennett *et al*., 2017; Kaplan-hallam and Bennett, 2017; Turgeon *et al*., 2018). ICES (2020b) supports EBM through the development of ecosystem overviews, and has a commitment to use the principles of EBM in science delivery. As such, they developed a short video and published illustrated manuscripts to communicate their vision and objectives for EBM to stakeholders and the general public (Thébaud *et al*., 2017; Link *et al*., 2019a; ICES, 2020c). The ICES Workshop on an ecosystem-based approach to fishery management for the Irish Sea engagement with harvesters in the development of an ecosystem model has led to new tools to identify fishing mortality ranges (F_{eco}) that consider multiple ecosystem components (Bentley *et al*., 2021; Howell *et al*., 2021). Such efforts improve the transparency regarding targets and objectives that allow for the co-development of EBM research questions. Expertise in facilitation can help to identify necessary ethical or engagement processes to build effective and long-lasting working relationships and communities of practice that are necessary to make EBM possible (Reid *et al*., 2021; Karcher *et al*., 2022; Maund *et al*., 2022; Ballesteros *et al*., 2023; Hatch *et al*., 2023; Parlee *et al*., 2023).

Step 2. Developing and selecting indicators

Indicators act as proxies to simplify or represent trends in an SES. Often the most useful indicators are those that capture emergent properties, cumulative impacts, and indirect effects (Methratta and Link, 2006; Link *et al*., 2015; Bundy *et al*., 2019). In short, indicators are the bases that allow changes in SESs to be measured (Otto *et al*., 2018; Bentley *et al*., 2019; Tam *et al*., 2019). Indicator development at the SES level for uses in marine EBM has focused mainly on ecological indicators (e.g. Large *et al*., 2013; Tam *et al*., 2017b), although there are a number of social-cultural and economic indicators that are currently operational (Colburn and Jepson, 2012; Himes-cornell and Kasperski, 2015; Pollnac *et al*., 2015). Indicators of human dimensions are becoming more useful to compare ecosystems at the national level that span different oceans. NOAA-Fisheries currently has 28 national-level indicators reflective of EBM objectives, thirteen of which reflect human dimensions while only five are biological (NOAA-Fisheries, 2023b). Thus, there is a high importance and need for SSH contributions for Step 2 of the IEA process in the US, but likely also in other regions as well.

Many operational SSH indicators are economic in nature and primarily *evaluative* (Table 2). Fisheries economists have contributed greatly to developing economic indicators with long time series (e.g. commercial fishing revenue and coastal community gross domestic product). However, social-cultural indicators (e.g. cultural attachment, health and wellbeing, and community sustainability) and governance indicators (e.g. environmental justice and procedural equity) are more difficult to use in an IEA because they often do not fit into the mould of traditional indicator criteria such as those developed by the ICES Working Group on Biodiversity Science (DePiper *et al*., 2017; Hornborg *et al*., 2019; ICES, 2021b) or specific, measurable, achievable/assignable, relevant, and time-bound (Doran, 1981) and are in some cases qualitative. The meaningful consideration and integration of Indigenous knowledge or traditional ecological knowledge into the IEA process may involve exploring cultures (e.g. values, practices, and ways of knowing) and indicators that differ from or contradict hegemonic cultural norms or epistemologies. This requires flexible methods that can integrate information across different scales (Kassam *et al.*, 2018). There are methodologies within the SSHs to assess qualitative indicators, including interpretative-based methods, surveys, and mixed-methods approaches.

Davenport and Anderson (2005) use interpretive-based methods to identify indicators or meanings for sense of place to community members surrounding the Niobrara River, Nebraska. Such methods rely on the subjective nature of real-world phenomena, using inductive or theory-generating data through open-ended questions to community members and analytical techniques where individual interviews were coded and summarized to explore common narratives (as opposed to deductive or theory-testing techniques). A survey that was co-developed by Parlee *et al.* (2023) included open-ended questions to understand changes in fishing efforts. In future applications of the survey, administered regularly (every 3–5 years), the results identified through inductive coding could be used as indicators connected to objectives for the fishery and incorporated in an SES model (Burnham *et al.*, 2022; Pourfaraj *et al.*, 2022). Biedenweg *et al.* (2017) used methodologies in anthropology, sociology, psychology, and geography to co-create indicators of community well-being amongst stakeholder groups in Puget Sound in the United States. Using a snowball sampling approach, they collected information from interviews, literature reviews, and stakeholder workshops to develop indicators that measure the psychological construct of hedonic well-being (e.g. feeling pleasant). Such methodologies can assess regionally specific social-cultural changes in human well-being.

With a high number of existing indicators, in some cases, it can be difficult to select a suitable representative suite of indicators to answer an EBM question. *Facilitating* and *anticipating* ensures that rightsholders and stakeholders objectives are represented and that indicators reflect the concerns of all participating groups. Delphi methods commonly used within future studies (Table 1; Okoli and Pawlowski, 2004) are often used to select indicators, whereby candidate indicators are ranked by groups of experts by predetermined criteria (e.g. ability to measure targets or objectives). This can involve a hierarchical selection process involving sub-criteria or multiple rounds of selection (Biedenweg *et al.*, 2017; Tam *et al.*, 2017b; Bundy *et al.*, 2019).

Step 3. Assess SES (ecosystem) trends and status

The primary theme for SSH input in Step 3 is *evaluating* (Table 2). Methods and analyses are generally similar for assessing trends and status across both SSH and natural sciences; the main difference between the two fields is the lens or worldview through which an SES status is evaluated. Much of the early inception of IEAs was focused on human and environmental impacts on the structure and function of an ecosystem (e.g. impacts of warming ocean temperatures on commercial fish species). However, over time, there has been a shift in focus towards considering the protection and sustainability of human life as part of the SES (Rockstrom *et al.*, 2009; Kasperski *et al.*,). Additionally, SSH considerations are necessary for effective solutions (Ostrom, 2009). Utilizing expertise in behavioural sciences, sociology, and psychology can help select indicators, analyses, and products that resonate with communities and end-users to ensure continued engagement and input into IEA processes (Samhouri *et al.*, 2014; Pahl and Wyles, 2017; Harvey *et al.*, 2021). More importantly, looking to such SSH disciplines for methodological support can help to incorporate and interpret traditionally difficult indicators such as emotions (e.g. anxiety and fear caused by management action) or human values (Jones *et al.*, 2016) as part of an SES (Meissner, 2016).

In this step, SES indicator data are assessed together to evaluate overall ecosystem status and trends relative to EBM targets and objectives. In many instances, when considering a full suite of potential indicators for an SES, the first step is to develop a conceptual or qualitative model or to enhance an existing model to better understand linkages between model components, identify data gaps, and to gain a common understanding between related groups about the SES (Zellner and Campbell, 2015; Voinov *et al.*, 2018; ICES, 2022b). Participatory modelling approaches are recommended for building such models, where they are iteratively created through a workshopping or collaborative process (Gray *et al.*, 2018; Jordan *et al.*, 2018). Bentley *et al.* (2019) incorporated fisher knowledge to enhance an existing ecological model to co-create indicators of food web structure through a multi-day workshop wherein government scientists worked alongside harvester groups and NGOs. DePiper *et al.* (2017) developed SES models for different regions across the Northwest Atlantic through an interactive process with a team including anthropologists, economists, oceanographers, biologists, and ecosystem modellers. There are many other examples of successful multidisciplinary and transdisciplinary processes to develop models to assess SESs (Pittman *et al.*, 2020; Reum *et al.*, 2021; Ferriss *et al.*, 2022; Pourfaraj *et al.*, 2022; Olsen *et al.*, 2023). Once the foundational understanding of how the indicators are interconnected in SES, quantitative end-to-end models, models of intermediate complexity, or individual indicators can be examined to determine the underlying causes for the observed SES status and trends (Buren *et al.*, 2014, 2019; Gaichas *et al.*, 2017).

There are a number of analytical methods to quantitatively assess SES indicators against historical reference points. Many marine management or IEA products such ecosystem status reports often examine time series data for selected indicators, positive or negative trends are determined typically through statistical analysis (e.g. generalized linear models), and status is determined from a long-term or short-term mean as a reference point or benchmark (ICES, 2023; NOAA-Fisheries, 2023a). Other studies have examined indicators across pressure gradients to develop ecosystem-level reference points or thresholds (Samhouri *et al.*, 2010, 2017; Large *et al.*, 2013, 2015; Tam *et al.*, 2017a; Otto *et al.*, 2018). These thresholds can be used as targets or avoidance points for certain indicators or indicator groups. Similar methodologies work with human dimensions indicators and pressures that have a long enough time series (e.g. Tam *et al.*, 2017a); however, in some instances, the time series is not long enough or the data are qualitative. In this case, qualitative but directional indicators can be matched with objectives. For example, the objective of increasing collaborative and inclusive governance structures in a marine spatial planning decision might be tracked through: The number of representatives involved in an IEA working group, the frequency of meetings or workshops, the themes that are discussed, how internal conflict is dealt with, and the implementation of decisions that are reached by the governance structure (Parlee, 2016). Spatial or geographical examinations of SES indicators are another promising methodology to assess ecosystems or SESs (Ellis *et al.*, 2012). Well-being indicators can be examined across coastal communities in different spatial management regions to determine their status. This can help to alleviate some of the time series data requirements that cannot be met (yet) by some human dimensions indicators.

Step 4. Assess risks and uncertainty

With a well-refined suite of objectives and indicators and examination of the whole SES, a risk assessment can be conducted to assess and *evaluate* risks to indicators (Table 2). Here, risk is defined as the magnitude and level of (un)certainty of an impact from one indicator to another and the measure of this impact from a baseline or reference point (i.e. risk of not achieving an objective). Generally, risk assessment approaches for both SSHs and natural sciences follow similar frameworks of (i) a triage phase to prioritize risks in achieving management objectives, (ii) using quantitative methods where possible, and (iii) including the level of uncertainty of the information in the assessment (Hobday *et al.*, 2011; Samhouri and Levin, 2012; Cormier *et al.*, 2017; Stelzenmüller *et al.*, 2018; Duplisea *et al.*, 2021; Roux *et al.*, 2022). Gaichas *et al.* (2018) used international standards for risk assessments (ISO, 2009) to develop participatory approaches to identify risk elements using identified objectives, indicators, and assessments from previous ICES WGNARS work (ICES, 2017) as base information to build a more defined risk assessment. Through this process, definitions and levels of risk were identified through expert opinion to SES indicators identified as risk elements (indicators directly linked to management objectives). Similar approaches have been used in mental health practices to identify and quantify psychological risks among social groupings (e.g. for children) for specific activities that do not necessarily have empirical assessments of such risks (Wendler *et al.*, 2005). Thus, such *evaluative* and methodological contributions to Step 4 from SSH could come from many disciplines and sources that examine risks.

Historically, IEAs have only considered human dimensions as sources of pressure or stress on ecological components, rather than viewing aspects of sustainable human communities as something that can be managed, conserved, or contributed to conservation. For example, it is increasingly recognized throughout the world that many Indigenous resource management practices improve yields of certain species in a sustainable manner (Ulluwishewa *et al.*, 2008; Thornton *et al.*, 2015; McGreavy *et al.*, 2021; Schmitt, 2021). While many risk-based frameworks in marine management primarily focus on human activities or environmental impacts affecting marine resources, the methodologies for assessing ecological, social-cultural, or economic risks from direct pressures remain similar (Cormier *et al.*, 2017; Holsman *et al.*, 2017; Stelzenmüller *et al.*, 2018; Roux *et al.*, 2019, 2022; Andersen *et al.*, 2022). The difficulty when considering risks in a complex SES is in identifying the risks of indirect impacts and assessing cumulative risks. Elliott and O'Higgins (2020) suggest including "basic human needs," derived from a hierarchy of human needs and welfare developed from research in psychology as a driver or pressure indicators of human activities in the SES. By including these latent drivers, the impacts of these activities on human welfare can then be tracked in terms of benefits obtained by society. Feedback from management actions can also be linked back to such indicators, offering a more accurate depiction of risks of management decisions to human well-being. Stelzenmüller *et al.* (2018) identify a risk framework for cumulative effects assessment that measures the risk of additive cumulative pressures surpassing an acceptable level. A structured risk evaluation then compares the results with established risk criteria and benchmarks to determine the significance of the level and type or risk. Through a standardized risk framework, cumulative impacts in an SES can then be examined together in a risk matrix to build a full picture of risks associated with SES management decisions. Well-developed visual aids for presenting risk to managers are recommended, as they are often better for *communicating* complex subjects to diverse audiences (Brennan, 2018; Stelzenmüller *et al.*, 2020).

Scenario planning is another method to identifying risks in decision-making that has been used extensively in business economics (e.g. financial planning) and futures studies (Shoemaker and van der Heijden, 1992; Ringland, 1998). This method identifies uncertainties in future projections from multiple contexts, such as global markets or novel industries, and helps to determine options that will help to meet management objectives across multiple sets of future conditions (Thorn *et al.*, 2020). Additionally, participatory scenario planning has become an important approach to identify risks and vulnerability in SESs from climate change (Weeks *et al.*, 2011; Flynn *et al.*, 2018). The Mid-Atlantic Fishery Management Council (2023) is in the later stages of their participatory East Coast Climate Change Scenario Planning process, where they are developing scenario narratives to identify risks for future fishery management and suggest recommendations for changes to existing approaches. Such processes require transdisciplinary knowledge and expertise in *facilitating* and *communicating* to collect and consolidate information from multiple contributors. Transdisciplinary work also ensures consensus and common understanding among these contributors regarding the developed scenarios.

Step 5. Evaluate management strategies and trade-offs

Once an understanding of risks and vulnerabilities to the SES are identified, management strategies or scenarios are selected to examine objectives defined through indicators by rightsholders and stakeholders in previous steps. The outcomes of applying these management strategies can then be explored through one or many operating models to *evaluate* the potential trade-offs among the management objectives (Table 2). In the initial synthesis of the IEA, a fully quantitative, ecosystem-level management strategy evaluation (MSE) was recommended (Smith *et al.*, 1999; Levin *et al.*, ; Kaplan *et al.*, 2021). Although such methods are rigorous, they require a high technical capacity and often have limitations in the ability to incorporate relevant SSH information. More recently, this step has been adjusted to be less daunting and to include multiple methods to analyse strategies. Harvey *et al.* (2021) expanded on a suite of analytical tools that could be used to present trade-offs such as qualitative methods (DePiper *et al.*, 2017; Reum *et al.*, 2021) and scenario analysis (Levin *et al.*, 2014) that are less time-consuming than MSE, and can incorporate qualitative or fuzzy-quantitative information.

There are a number of ways to develop operating models for SESs to which management strategies are applied and outcomes are examined. Furthermore, there are many examples of operating models for evaluating management strategies built from collections of multiple datasets. Many of the large-scale, quantitative, end-to-end models involve using collations of such datasets (Smith *et al.*, 1999; Fulton, 2010; Kaplan *et al.*, 2021). Other methods involve a participatory approach to model development. Reum *et al.* (2015) developed a model for multi-sectoral uses of Puget Sound through a workshop process with stakeholders. Zellner *et al.* (2022) used participatory modelling approaches for environmental planning and indicated that stakeholders are more willing to engage in models that hit the "sweet spot" in terms of complexity. Good *facilitation* in developing or selecting models is key for participatory approaches. Facilitation could be provided by individual(s) internal to a transdisciplinary IEA team, or through an external, neutral third party (Gray *et al.*, 2018; Maund *et al.*, 2022). This can result in higher levels of engagement and trust with rightsholders, stakeholders, and decision makers, and provide a better overall understanding of potential outcomes.

In most evaluations of management strategies, there is no single optimal outcome to meet objectives, and trade-offs that have to be made. With inherently complex problems associated with SESs and EBM, a number of compromises need to be made between multiple objectives when considering the many interactions. Thus, clear *communication* regarding the nuances between the various trade-offs in meeting objectives is an important consideration for those working towards a decision. Examples from economics, business, and management sciences show that multiple considerations beyond profits need to be examined in both the short and long term. Dichmont *et al.* (2010) noted the importance of practicality when examining long- and short-term trade-offs in management scenarios using multi-species bioeconomic models. Long-term optimal scenarios for fisheries can involve a short-term reduction in fleet for a given fishery, but if there is no access to alternate fisheries, it is impractical (or unethical) to knowingly impose adverse situations on a fleet when an alternative path may exist. Daw *et al.* (2015) used a participatory approach coupled with a SES toy model (example model) that was able to communicate a wider and more nuanced variety of trade-offs and to allow stakeholders to think more holistically about potential outcomes. They were able to learn and develop trust regarding such modelling techniques. Complex EBM problems require transdisciplinary approaches to confront trade-offs that involve a blend of model-based adaptive management strategies to help understand uncertainty under differing management scenarios and participatory research that involves rightsholders and stakeholders input to facilitate an equitable decision-making process under that uncertainty.

Step 6. Implement management action

In our view, this step in the IEA framework should lean heavily on understanding the governance and management processes for EBM in Step 0. From a purely natural science perspective, the IEA information produced from the previous steps should simply be passed on to EBM decision makers and implemented (Levin *et al.*, ; Samhouri *et al.*, 2014). However, a lack of understanding and recognition for institutional structure and functioning (as opposed to scientific knowledge) has been identified as one of the persisting problems to implementing ecosystem approaches like EBM (Soomai, 2017; Kelly *et al.*, 2019). There are numerous ways in which transdisciplinary IEA teams can be more impactful for *communicating* and *facilitating* in this step, as it lies at the science-policy interface (Table 2). Some SSH experts have the skills and knowledge needed to identify which individuals or teams are involved in the governance and management of a resource, in addition to how and when they are able to make interventions throughout those processes (Reed *et al.*, 2009).

Generally, improving communication ensures that the selected management scenarios are clearly presented to decision-makers and trade-offs are understood. Uncertainties also need to be understood and accepted. The risks of selected management scenarios from the IEA process should also be contrasted with the risk of not taking any actions. Soomai (2017) explored the informational pathways of science to decision-making in Canadian fisheries through the lens of information management, and concluded that understanding the culture and movement of information through an organization is essential to finding pathways to include new types of knowledge to decision-making. Bottom-up recommendations to increase dialogue between scientists and decision-makers develop wider communities of practice, and remove scientists and resource managers from their defined siloes have also been broadly acknowledged (Samhouri *et al.*, 2014; Skern-Mauritzen *et al.*, 2015, 2018; Soomai, 2017). Other global experts on the science-policy interface also advocate for top-down, direct engagement of scientists (or potentially rightsholders and stakeholders) to the development of policy (UN, 2013).

Step 7. Monitor SES indicators and management effectiveness

Monitoring the effectiveness of management actions in terms of indicator-based decision-making is an important step in the IEA framework. Tam *et al.* (2019) suggest including such management decision feedback into end-to-end modelling frameworks to be able to explore outcomes of ecosystem-level decision-making. This can help to *evaluate* the frequency of monitoring efforts under limited budgets and capacity. It also ensures that indicators continue to be responsive to changes to pressures (Fu *et al.*, 2019). However, utilizing quantitative modelling as the basis for monitoring should perhaps only be part of the process. Collaborative monitoring programmes between related groups and government scientists can be a valuable mechanism to bring various data sources together (e.g. natural, science, and experiential) and where communities can voice their priorities and concerns. In Canada, Marine Protected Areas, National Marine Conservation Areas, and Indigenous Protected and Conserved Areas policy encourages community monitoring programmes to preserve important ecological, cultural, and social features that are significant to coastal communities (ECCC, 2022; PCA, 2022; DFO, 2023). Bottom-up monitoring efforts through organizations such as the Fishermen and Scientists Research Society (FSRS, 2023) *facilitate* partnerships for research and monitoring between harvesters and scientists that promote the sustainability of marine fisheries.

Such collaborations are based in the recognition that both scientists and harvesters have valuable contributions towards effective long-term stewardship of marine resources. Berkes *et al.* (2007) document collaborative research regarding climate change and note the importance of community monitoring projects in the Canadian Arctic. One study on the inuit observations of climate change illustrates the significance of traditional knowledge in evaluating and communicating the local impacts of climate change by monitoring access to resources, safety, predictability, and species availability. The results of the project were a report to *evaluate* (Castleden and Ashford, 2002) and a video production to *communicate* climate change effects from the perspective of the Inuit community of Sachs Harbour (IISD, 2002). Such collaborations between rightsholders, stakeholders, natural scientists, social scientists, and those who work in humanities led to effective communication networks to link robust science to decision makers (Berkes *et al*., 2007).

More and more governments are emphasizing environmental justice as a part of good governance, which includes an increase in equity and transparency of data, processes, and products that are publicly funded (UNSD, 2019). The concept of open data, and equity and transparency in data, requires consideration given the context of what is being researched, by whom, and for whom (Bastille *et al*., 2020). Monitoring indicators require information and data that are often done by separate agencies and institutions. There can be contrasting approaches, or a spectrum of what equity in data management and data sharing might look like (e.g. DFO, 2019; OCAP, 2023). The implications of these approaches are very different from natural and social science perspectives since documenting data about the natural world is arguably less sensitive than dealing with information about people's values, livelihoods, knowledge, and experiences. SSH researchers need to think about the implications of research involving humans and, in many cases, have to demonstrate that the benefit of research outweighs the risks to people involved (e.g. social harm and legal harm). Once the type and source of data required to monitor indicators have been identified, obtaining the data may rely heavily on relationships developed through previous IEA steps and require collaborative governance arrangements in order to access the data or formal processes such as data sharing agreements.

Step 8. Evaluate and assess outcomes

While it has been recognized that evaluating the outcomes of management actions is an important step for successful IEAs (Samhouri *et al*., 2014), in practice, this has been difficult and poorly done. Understanding the distinction between outputs and outcomes and the timeframe in which they are evaluated are important to measuring the success of either. The metrics commonly used to evaluate management outcomes are tool-oriented outputs (e.g. novel analytical methods) or product-oriented outputs (e.g. reporting, peer-reviewed journal articles) and do not reflect the process-oriented outcomes of the IEA framework (Harvey *et al*., 2021). The measure of success of outcomes from a process is often complex or long-term and cannot always be captured in the same way as the tools or products that are derived from the process (Stojanovic *et al*., 2004; Cvitanovic *et al*., 2021, 2022). Often, successful tools and products do not necessarily speak to the effectiveness, success, or completion of initial desired outcomes of a process (e.g. building and maintaining relationships). In the context of IEA, it is suggested that the process, tools, and products be evaluated together to have a more positive and holistic view on what has been accomplished.

There are methods and processes in SSH disciplines that could be beneficial to *evaluate* the overarching outcomes and outputs of the IEA process (Table 2). Self-reflection is an important component of a lot of SSH research due to the recognition and application of social theory. As a result, many social scientists and those who work in humanities are more aware of the implications of one's own bias on the outcomes of research and often apply continuous self-reflection using a variety of tools to achieve a full evaluation of the research (Finlay, 2002; Olmos-Vega *et al*., 2023). Both Foucault (1969) and Bourdieu (1990) emphasize the importance of self-reflection in social science research with conscious attention to the effects of their own position (power dynamics) and how this can distort or prejudice objectivity. Both utilized multidisciplinary examinations in philosophy, history, psychology, and political science to review cases and document biases in social science research. Such examples show that reflecting on the contextual grounding and the progress of the research itself can enable researchers to understand and account for knowledge biases in processes such as an IEA. Posner and Cvitanovic (2019) explore both objective and subjective evaluation methods to track the impact of transdisciplinary teams working at the science-policy interface. They note the practical importance of measuring such impacts to create productive dialogue, justify investments, and differentiate the impacts of various overlapping activities. Lindkvist *et al*. (2022) reflected on the development of a methods portfolio (collection of methods) for tackling sustainability challenges in SESs for fisheries. They acknowledged how the development of a method portfolio itself could be influenced by the initial motivations of the researchers and the research questions, they concluded that there were multiple pathways to achieve a methods portfolio and acknowledged the advantages and limitations of the approach they took. This is critical knowledge for iterative processes such as IEAs, where lessons learned are hugely beneficial to future IEA cycles. Better and more explicit documentation of self-reflection in IEA processes would benefit the overall IEA framework.

Discussion

With the clearer definitions of SSH disciplines and branches provided in this paper, it is possible to recognize SSH more comprehensively in EBM. The paper offers guidance to move away from the prevalent misconception in marine management processes that all social scientists are alike in their expertise and skill sets (van Putten *et al*., 2021). As discussed above, the breadth and diversity of knowledge available through SSH disciplines and branches can help move IEA and EBM efforts forward, addressing long-standing calls for stronger incorporation of human dimensions into EBM (Link *et al*., 2017). Incorporating more diversity, perspectives, and skills from SSHs into an IEA process will add value in: filling gaps in expertise, including multiple worldviews, exploring a wider range of available methodologies, ensuring ethical practices in the delivery of science, improving efficiency in facilitating work between a variety of audiences, and enhancing the effectiveness of science solutions. Having a deeper understanding of multiple worldviews and the ways people can create and process knowledge offer huge insight into the complex nature of producing scientific advice for SES-level decision-making, and the creative pathways to solve related problems. There were some key considerations identified to effectively incorporate SSH roles and disciplines into the IEA process:

1. *The need for specific SSH disciplines and branches will be context specific to the research question (IEA or otherwise), availability and context.*

Multiple SSH disciplines were connected to each theme, and thus multiple disciplines could be used to address IEA questions. Many SSH disciplines imply formal training in similar methodologies. For example, a demographer might have a very similar skillset to a human geographer; or a linguist might have similar capabilities as a communications expert. Thus, finding the right fit for an IEA team will be dependent on the particular research questions or objectives and the available expertise within the region. The tables provided in this paper are a good place to start when considering assembling or adding to an IEA team.

2. *Transdisciplinary teams are best, multidisciplinary teams are great, external expertise is extremely beneficial.*

Typically, IEAs have been primarily natural-science led to contribute to EBM decision-making. As such, it can be difficult to assemble fully multidisciplinary or transdisciplinary teams, and some governments have been making investments into developing internal capacity for SSH. Progress is slow (Olson and Da Silva, 2021). It is worthwhile to explore the regional SSH capacity when fully integrated government social science programmes are underdeveloped and many potential SSH disciplines exist. Developing long-term relationships between government and academic partners can be extremely effective to moving IEA programmes forward. Collaboration/networking hubs and international strategic initiatives can also be a great source to connect and build teams with SSH expertise. The authorship of this paper was partially assembled through a request to the ICES Strategic Initiative in Human Dimensions (ICES, 2022a). Other organizations promote boundary spanners (individuals or groups that facilitate the exchange between the production and use of knowledge to support evidence-informed decision-making) as a beneficial component to bring diverse groups together in decision-making processes, including those with SSH skills (Posner and Cvitanovic, 2019; Karcher *et al.*, 2022).

3. *Long-term investment is required to better integrate SSH into IEAs.*

It is clear that IEAs and EBM require top-down and bottom-up investments, including staff, resources, and time. These investments need to include training in the SSHs and hiring of staff with skills to coordinate SSH roles and interpret SSH disciplines. Unfortunately, short-term investments (<4 years) may not be sufficient to complete and fully integrate SSH theories and methods into an IEA cycle. The process-oriented focus of IEAs does not lend itself to short-term success, although it is noted that there are short-term IEA products that have significant impacts and are worth doing. In an ideal scenario, IEAs require a continuation of institutional knowledge, in that researchers (and as much as possible, external contributors) remain consistent and stable. Without an investment in SSHs embedded in some way within institutions, the added value to the IEA process from SSHs will unlikely go beyond the selection of indicators.

One of the primary concerns regarding IEA implementation is high costs involved in doing such work. Link *et al.* (2019b) propose considering transaction costs—the costs of information gathering, coordination, negotiation, litigation, monitoring, and enforcement—through methods in institutional economics to evaluate the cost-effectiveness of alternative governance arrangements. Utilizing such information and methods could streamline efficiencies and costs in developing and continuing IEAs. Also, such methods could explore the costs of not addressing EBM questions through IEAs and the risks involved in not taking comprehensive actions at the SES level.

4. *Decision-making is complex and difficult, and involves both objective and subjective knowledge.*

Every step in the IEA framework involves decision-making by the IEA team, rightsholders, stakeholders, and decision makers. Academic research in decision-making is an SSH branch unto itself that has been touched on in this paper. Here we propose that both the IEA process and EBM require an understanding and exploration of how positivist, interpretivist, and constructivist worldviews influence decision-making at all levels (e.g. individual, community, and regional). Mainly positivist worldviews have thus far shaped the IEA process. While governments have prioritized the pursuit of evidence-based decision-making, the reality/realities is/are that objective truths (facts) coexist with subjective truths (beliefs and opinions), and both should be accounted for in decisions that ultimately impact humans. Many social scientists and those who study humanities have experience grappling with subjective data and are able to analyse and make sense of such information. Many new disciplines and branches within SSHs attempt to blend the two schools of thought. Ecological accounting, for example, aims to combine valuations of ecosystem services while also acknowledging that some ecological features are intrinsically important, but have no specific value (Russell *et al.*, 2020). Perhaps natural scientists can learn from acknowledging and embracing subjectivity in their research.

5. *The generative capacity of underused disciplines for enhancing the IEA process should not be underestimated.*

While this work primarily focuses on the contributions of SSH disciplines to IEAs and EBM, there are many ways in which other underused disciplines, even some outside of the SSHs, could be useful in enhancing IEAs for EBM. There were many instances where examples or methods from various professional disciplines (e.g. medicine, engineering, and teaching) could also contribute to the IEA process, but were not fully explored. Ultimately, this is because decisions need to be made by everyone all the time. Difficult decisions, with significant or complex trade-offs, are prevalent outside of the marine management context. (How do you deliver a difficult diagnosis? How can we gain efficiency in producing a product? How do we create a good environment for learning?) Natural scientists involved in developing scientific support for decision-making can learn from other disciplines and worldviews, include others in the conversation, and apply some creative thinking to address issues encountered within the IEA process.

Conclusions

The purpose of creating this paper was not to provide prescriptive advice or best practices with regards to SSHs in IEAs, but rather to provide guidance to improve SSH support in a typically natural-science-led process. This was also an opportunity to update the IEA framework by collating new information and methods that have been explored since the last examination of the IEA loop into each of the individual steps. In many ways, the IEA framework is "evergreen," and reflecting on the framework itself has clear benefits towards making the process better through the inclusion of SSHs.

There are many actionable strides that can be taken to enhance the roles and utilize the skillsets within SSH disciplines to advance IEAs and EBM. Such steps require support for SSH practitioners to be engaged earlier and more often in transdisciplinary processes. Appropriate funding for long-term transdisciplinary work and the governance mechanisms to include outcomes of such work in decision-making are also required. Through this, a wider variety of methodologies can be considered in these processes, including inductive methods more commonly used in interpretivist and constructivist research to more comprehensively move towards operational EBM.

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Supplementary material

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Author contributions

JCT was responsible for conception, development, writing and editing of this manuscript. CEP, JC-M, VP, MB, and AC made significant contributions to the conception, development, and editing of this paper. JB contributed to development, editing, and visualizations. EJA, SE, GB made contributions to development, and edits of the manuscript.

Conflict and competing interests

The authors declare no conflict of interest and no competing interests.

Data availability

Data generated from group discussion or literature review that underly this article are available in the online supplementar y materials.

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