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Comparison of the definition, core concepts, major uses, place in management/policy and observations on relative strengths and weaknesses of six sustainability-related concepts

Sustainability Concepts

Social-Ecological Systems (SES)

SES are complex, integrated systems in which humans are part of nature (Berkes and Folke 1998). Defined by (Berkes 2011) as an "integrated complex systems that include social (human) and ecological (biophysical) subsystems in a two-way feedback relationship". The SES (should) give equal attention to the social and the ecological system and the interlinkages between them. The review of Colding and Barthel (2019) provides a range of definitions for a social-ecological system: "a system of people and nature" (Thomas et al. 2012) -a system "where social and ecological systems are mutually dependent" (Fidel et al. 2014; p.48); "interdependent and linked systems of people and nature that are nested across scales" (Bouamrane et al. 2016); "a system that includes societal (human) and ecological (biophysical) subsystems in mutual interactions" (Harrington et al. 2010; p.2773); a system that "includes the entities of common-pool resource, resource users, public infrastructure, infrastructure providers, institutional rules, external environment and the links between these entities" (Özerol 2013; p.73); and "complex adaptive systems with key characteristics such as: (1) integrated biogeophysical and socio-cultural processes, (2) self-organization, (3) nonlinear and unpredictable dynamics, (4) feedback between social and ecological processes, (5) changing behavior in space (spatial thresholds) and time (time thresholds), (6) legacy behavioral effects with outcomes at very different time scales, (7) emergent properties, and (8) the impossibility to extrapolate the information from one SES to another" (Delgado-Serrano et al. 2015).

Folke and Berkes (1998) developed the concept as an analytical framework for the study of the linkages between ecosystems and institutions (although the term had been coined in 1970, and was used by (Cherkassi 1988; p.321) to denote interacting biological and social subsystems (see Colding et al. 2019)). The social-ecological systems (SES) approach has, from the beginning, been tied to institutional resilience, and how institutional resilience may be combined with ecological resilience for mutual benefit (Folke et al.

1998). The SES framework was used by Ostrom and colleagues to investigate institutional arrangements that would enable actors to work together and solve social dilemmas in systems with common-pool resources (CPR) and public goods. Development of the SES has been influenced greatly by collective action theory and application to studies of situations involving small-scale common pool resources (Partelow 2018). The SES approach is linked with ecosystem services (Daily 1997, Partelow and Winkler 2016), resilience (Berkes et al. 1998), and a variety of other environmental governance theories (Folke et al. 2005, Cox et al. 2016), including multilevel governance, polycentric governance, and adaptive co-management. The concept of SES highlights that the boundary of social and ecological approaches is artificial and arbitrary (Moberg and Simonsen 2014). Understanding SES is to comprehend the feedback loops of human-nature interaction, the resilience of these systems in dealing with internal and external disturbances and, from that, how to make good decisions in managing these systems towards sustainability (Stori et al. 2017).

The SES approach has been used to evaluate community-based systems such as conflict and collaboration in situations such as irrigation systems (Hoogesteger 2015, McCord et al. 2016), small-scale fisheries (Blythe et al. 2017, London et al. 2017, Partelow 2018) and forestry (Fleischman et al. 2010, Oberlack et al. 2015, Davenport et al. 2016).

SES is largely conceptual and based on theories of social-ecological systems (Ostrom 2009, Pickett et al. 2011, Cook et al. 2012, Opdam 2013). Partelow (2018) notes that the SES framework has been applied mostly to small-scale common pool resources, although a few papers have recently begun to shift the focus to large-scale commons (Epstein et al. 2014, Ban et al. 2015, Ban et al. 2017) and hybrid or overlapping commons like coastal systems (Schlüter et al. 2019).

The SES approach is not explicit in any policies or international agreement. Rather, it is a largely academic framework for analysis and comparison. Partelow (2018) points out that it has the strength of being a general but adaptable framework that enables comparison, as well as a good diagnostic tool for development of theory.

Partelow (2018) demonstrated a bias towards consideration of social system variables, most likely due to the development and almost exclusive use of the framework by social scientists. Colding and Barthel (2019) note that a lack of a common analytical framework of SES poses significant challenges for the emerging field of SES (Schlüter et al. 2012), a more precise definition is also warranted to avoid the risk of the SES discourse becoming diluted (Marshall 2012). Colding and Barthel (2019) suggest the need for a more thorough definition, that should at least embrace the well-known social-economic-ecological triad inherent in the notion of sustainable development. Partelow (2018) suggests integrating the framework with other conceptual and theoretical frameworks to expand its usefulness for contributing to other theories and frameworks in associated fields such as ecosystem services, sustainability science, the Coupled Infrastructure Systems framework, and resilience theory.

Ecosystem Approach to Management (or Ecosystem Based Management) (EAM)

Definitions and understandings of an ecosystem approach are based on Brundtland-Sustainability (WCED 1987) and build upon the three dimensions - ecological, societal (including social, cultural, economic), and governance. The FAO, for example, states that an ecosystem approach to fisheries "strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries" (FAO 2003). Multiple definitions of an ecosystem approach exist, but attempts have been made to converge them, especially in North Atlantic-based jurisdictions, which can be captured by the following: "an integrated adaptive management approach to help marine managers consider trade-offs to protect and sustain diverse and productive ecosystems and the services they provide. Informed by science, it incorporates the entire ecosystem, including humans, into management decisions" (AORA 2019). More simply, this approach aims to balance "human activities and environmental stewardship in a multiple-use context' (Smith et al. 2017), although many variants exist (e.g. McLeod and Leslie 2005, Long et al. 2015, Patrick and Link 2015). The terms Ecosystem-Based Management (EBM) and an Ecosystem Approach to Management (EAM) are both used, and although there are nuanced differences between them (Link 2010), they are typically used interchangeably by the international community (Marshak et al. 2016).

The Brundtland concept of sustainability and development of an ecosystem approach was reflected in the Convention on Biodiversity developed in Rio de Janeiro, Brazil (CBD 2003), which called for conservation of biological diversity through an ecosystem approach. 'The ecosystem approach provides a guiding strategy for the implementation of integrated management (IM) of land, water and living resources that promotes conservation and sustainable use in an equitable way. Thus, the application of the ecosystem approach will help to reach a balance of the three objectives of the Convention: conservation; sustainable use; and the fair and equitable sharing of the benefits…' CBD (2003). First implemented in the management of terrestrial parks (Grumbine 1994), and although primarily focused on ecological and conservation objectives, it recognized the need to consider the interactions of humans with ecosystems - "Along with defining the ecosystem management approach as a new policy framework there appears to be a parallel process of re- defining the fundamental role of humans in nature" (Grumbine 1994). An ecosystem approach started to be considered in the marine world during the 1990s, epitomized by, e.g., Canada's Oceans Act (1996), South Africa's Marine Living Resources Act (No. 18 of 1996) and Australia's Ocean policy (1998). In Europe, it was written into the common fisheries policy and has been implemented as the Marine Strategy Framework Directive or MSFD (ICES 2005, EU 2008). Notably, it opened the door for a more holistic, inclusive and participatory approach, shifting away from the sole focus on hard predictability and towards indicator-based, semi-quantitative methodology or "soft predictability" (e.g. Degnbol 2003, Shannon et al. 2010, Shin et al. 2012). However, a shortcoming of these

remained that they were not really implementing EBM, but providing the natural science advice to inform EBM (e.g. Ommer 2007, Paterson et al. 2010).

The ecosystem approach has evolved to be fully inclusive of ecological, social, economic and governance considerations and inherently recognizes coupled social-ecological systems with stakeholders involved in an integrated and adaptive management process where decisions reflect societal choice. Long et al. (2015) identified 15 key principles of EBM, including integrated management, coupled social-ecological systems, interdisciplinarity, adaptive management and stakeholder involvement. EBM is the apex of an hierarchy of ecosystem approaches (Link and Browman 2014) that includes sector-based approaches, including ecosystem-based fisheries management (EBFM) e.g., "a holistic, place-based framework that seeks to sustain fisheries and other services that humans want and need by maintaining healthy, productive and resilient fishery systems" (Levin et al. 2018; p.49) and an ecosystem approach to fisheries management (EAFM, which includes consideration of ecosystem factors in the assessment of stock status" (Link et al. 2020). The North Atlantic Ocean Research Alliance (AORA 2019) identified the following six benefits from EBM: (i) optimize benefits among a diverse set of societal goals; (ii) identify trade-offs and benefits among activities and resources within an ecosystem; (iii) understand the cumulative impacts of a management action beyond just a single issue; (iv) help communicate risks, uncertainties, and implications of management decisions; (v) ensure more transparent decision processes; (vi) science-based EBM approach will enhance collaboration, leverage opportunities, and improve decision-making. However, ecosystem approach and implementation has not evolved at a similar pace globally and questions of stakeholder inclusivity and knowledge systems accepted as valid in the management discourse still need to be resolved in many parts of the world, and the scientific concept of trade-offs, stemming from the decision sciences, still needs to be widened (e.g. Daw et al. 2015, Jarre et al. 2018).

As a policy objective, EAM is the focus of many marine-oriented organizations, such as ICES, PICES, FAO, UNEP, and NOAA (Link et al. 2014, Rudd et al. 2018, Link et al. 2020). Marshak et al. (2016) argue that "It is clear that the discipline and practice of EAM is now at the point of exploring the how-to of executing EAM" and "and there is mutual agreement on the importance of more holistic approaches to marine EBM within a given region". There are still impediments, such as lack of knowledge, conflicting interests, lack of organizational/legal framework, and lack of communication (Marshak et al. 2016), but enabling policy exists. Rudd et al. (2018) reviewed the extent to which North Atlantic jurisdictions have a mandate for EBM/EAM, that is, whether governing authorities have the tools and authority required to effectively implement EBM and concluded that "most of the major ocean pressures and uses posing threats to ocean sustainability have some form of coverage by national or regional legislation", i.e. "there are adequate, existing mandates to authorize EBM" (Link et al. 2020). McCleod et al. (2005) correctly note that there is no one way to implement EAM, but there are rather many 'right ways', that will be implemented differently in different contexts (some examples are provided in Marshak et al. 2016, Link 2017, Smith et al. 2017, Langhans et al. 2019).

Integrated Management (IM)

Integrated Management (IM) is 'an approach that links (integrates) planning, decision-making and management arrangements across sectors in a unified framework, to enable a more comprehensive view of sustainability and the consideration of cumulative effects and trade-offs' (Stephenson et al. 2019). IM has also been called Integrated Coastal Zone Management or Integrated Coastal Management - 'the process of managing the coast and nearshore waters in an integrated and comprehensive manner with the goal of achieving conservation and sustainable use' (Katona et al. 2017) - and Integrated Oceans Management (IOM).

Integrated Coastal Zone Management dates back to the 1970s. The concept is apparent in the UN Convention on the Law of the Sea, negotiated between 1973 and 1982 (UnitedNations 1982) and the recognition that the problems of ocean space needed to be considered as a whole. Explicit calls for a comprehensive and holistic approach to IM of the marine environment strengthened after the United Nations Conference on Environment and Development (UNCED) in 1992. Further to a workshop held in 1989 by the Coastal Area Planning and Management Network, the term Integrated Management (IM) emerged as "a dynamic process in which coordinated strategy is developed and implemented for the allocation of environmental, sociocultural, and institutional resources to achieve the conservation and sustainable multiple use of the coastal zone" (Price and Khan 2014).

Examples of Integrated Management include:

- Integrated Management of the Australian NSW Marine Estate (Brooks et al. 2020); Integrated Management for the Australian Great Barrier Reef;
- Integrated management for the Barents Sea (Olsen et al. 2016)
- Integrated Management Plan for the North Sea;
- Integrated Management of the Canadian North Pacific Coast: Marine Plan Partnership for the North Pacific Coast (formerly PNCIMA);
- Canadian Beaufort Sea Integrated Management Plan and partnership

IM is an aspiration of many international agreements, including the Law of the Sea Convention (UnitedNations 1982), and is explicit in legislation in many jurisdictions including the EU Water Framework Directive and Marine Strategy Framework Directive (EU 2008, Borja et al. 2010), the Australian Oceans Policy (Vince 2012) and the Canadian Oceans Act (Jessen 2011).

IM, like EAM, encompasses the interconnectedness of natural systems, human systems and management (Bernal 2015). It explicitly emphasizes practical management of multiple sectors to achieve diverse objectives. As Winther et al. (2020) summarize,

> *'the goal of IOM is to support a sustainable ocean economy: long-term, sustainable use of ocean resources in ways that preserve the health and resilience of marine ecosystems and improve livelihoods and jobs, balancing protection and production. IOM brings together relevant actors from government, business, academia and civil society from the entire spectrum of ocean-related human activities (e.g., petroleum, fishing, aquaculture, shipping, tourism, mining, renewable energy, conservation) to collaborate toward a sustainable future for our ocean environment'.*

The primary weakness of IM is that it has been difficult to implement (Borja et al. 2008, Vince 2015), which is in a large part owing to the complexities of existing management jurisdictions and arrangements (Stephenson et al. 2019, Stephenson et al. 2019).

Marine spatial planning (MSP)

The most accepted definition of the Marine Spatial Planning is from UNESCO – "a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that have been specified through a political process" (Douvere, 2008). Therefore, as a process that seeks to mediate conflicts among users of marine resources, MSP recognizes the legal, political, economic and ecological complexity of ocean governance (Ehler and Douvere 2009). MSP can be defined as a spatially explicit, science-based, forward-looking 'analytical and use allocation' process designed to achieve a policy-driven set of ecological, economic, and social objectives. As such, it must ensure that multiple human activities are (co)developed within an Ecosystem Based Management (EBM) framework.

Operationalizing MSP can be defined in a series of steps (Ehler et al. 2009, Agardy et al. 2011). Relying on stakeholder involvement and decision-making at an appropriate level, through a continuous process of monitoring-evaluation-revision, MSP should entail a cyclical and iterative approach incorporating new information over time and adapting its objectives and measures according to the evolution of the socio-ecological system. During the past 20 years, the evolution of MSP has become a crucial step for sea management. The initial concept of MSP was stimulated by international and national interest in developing marine protected areas (MPAs); for example, the Great Barrier Reef Marine Park in Australia (Douvere 2008). However, more recently MSP is seen as a tool to manage the multiple uses of marine space, especially in areas where conflicts among users and the environment are already apparent.

MSP is being applied in a number of countries, with more programs being initiated each year. The majority of these programs were initiated after 2000. IOC-UNESCO has also developed a world-wide inventory of MSP activities (http://msp.ioc-unesco.org/world-applications/overview/) which reports that approximately 80 countries have implemented MSP in some form to date. Many of these activities are still developing management plans; relatively few have moved to implementation or revision of plans.

The Great Barrier Reef Marine Park (GBRMP) in Australia is commonly viewed as a "pioneering example of MSP" (Jay et al. 2013). The zoning of the GBRMP has been established through a continuous and adaptive process, involving stakeholders and ensuring sustainable financing. The original zoning plan of the Marine Park was further revised and adapted in 2003, and in 2009 and 2014 the five-year reports (examining the progress in the protection of the Great Barrier Reef, evaluating the effectiveness of the management, etc.) were published. In recent years the number of countries with MSP initiatives increased around the world (see the complete list at http://msp.ioc-unesco.org/world-applications/overview/). Over 70 countries around the world (IOC-UNESCO, 2020) are currently developing a MSP, and almost 70% of these are still in the early phases of their MSP initiatives (Santos et al. 2019). Worldwide, 22 countries have government-approved MSP plans place, representing almost 27% of the world's exclusive economic zones (EEZs) (Claus et al. 2017). These include cases in which MSP covers the majority of the maritime space (EEZ) (e.g., Belgium, Germany, the Netherlands, Norway, China, and Belize), but also countries where MSP is applied for just a particular area under national jurisdiction (e.g., United States, Canada, and Croatia). The Belgian MSP process is probably one of the most complete, having followed the theoretical MSP steps. Approved by Royal Decree in March 2014, and revised in 2017, it was subject to a large-scale and formal public consultation process in 2018. The public sent more than 40,000 contributions, and as part of the consultation process, a public hearing was organized; neighbouring countries were also contacted to provide their thoughts on the draft plan. Additionally, in order to make the geographical information in the Royal Decree accessible to a broad community of potential users, a marine data portal was developed (marineatlas.be). A new Royal Decree on 22 May 2019 establishing the revised MSP for the period 2020-2026 in the Belgian part of the North Sea areas; this entered into force on 20 March 2020. The Belgian MSP has a very comprehensive guidelines for management actions across several economic sectors, also addressing the management of human uses within protection zones and MPAs (Santos et al. 2019).

From its inception, many examples of MSP have been developed worldwide with objectives that could be considered divergent. For example, while some MSP aimed to meet renewable energy targets, others aimed to designate effective MPAs. It could be argued that all MSP focuses on achieving optimal trade-offs between a variety of ecological, economic and social objectives, as the main overall objective of the conceptual framework of the MSP, but in reality, MSP has often been driven primarily by a specific sector objective. A recent study by Jones et al. (2016) analyzed 12 different MSPs implemented around Europe in detail and concluded that: (1) Blue growth is the dominant priority within MSPs overall, often focusing more on sector-specific objectives than on strategic priorities at the national

level; (2) MSP case-studies tend to be fragmented (e.g. pilot activities) and develop in a practical way on an *ad hoc* basis, rather than a dynamic and adaptive process as prescribed in the conceptual framework of the MSP; (3) in most of the cases, MSPs tend to be implemented via top-down approaches and participatory platforms exist but are usually disconnected from executive decision making. Similarly, Domínguez-Tejo and colleagues (2016) performed a review of several MSP case studies, noting that the major shortcomings concerned the assessment of social values, including the lack of spatial representation of "social connections" with the marine environment and the lack of economic estimates not from the market. Overall cultural/heritage values were poorly represented in comparison to economic and environmental values.

There are many possible benefits from the implementation of MSP. It could allow the management of human activities through the conservation of important marine ecological processes and the overall resilience of the marine systems; could allocate spaces in a rational manner which minimises conflicts of interest and maximises synergies across sectors; could potentially manage spatio-temporal cumulative impacts and could also help to create a better linkage between science and management. For all these reasons, MSP has been recognized as a necessary tool to guarantee sustainable maritime development; i.e. EU Green Paper (EU 2006). However, as already mentioned, lately most national and European MSP initiatives seem to be focused on blue growth, often focusing more on sector-specific objectives than on strategic priorities at the national level. It may be noted that MSP is considered to espouse a relatively reductive, technocratic view of the field of ‘planning’ which, in urban planning, for example, is much more explicit in its social, cultural and economic aims, as well as its environmental aims.

Overall, the most important weakness of this approach is seen to be a lack of integration of the social, cultural dynamics across the MSP process (Gissi et al. 2018). A future challenge for MSP will be the implementation of an adaptive approach to ensure that the spatial planning, management, and development of policies in marine spaces can be constantly adapted, to enable and foster sustainability. Also, more attention should be dedicated to MSP as a way to foster synergies (Depellegrin et al. 2019).

Participatory co-management (PCM)

There is no single definition of co-management, but rather a diversity of forms or arrangements of institutions that reflect a particular context and political history. Accordingly, there are numerous descriptions of co-management in the literature, and with reference to wildlife, forests, parks and fisheries and oceans. Osherenko (1998), for example, described co-management as a: 1) system of rights and obligations for those with a shared interest or stake in a resource (e.g., fishery); 2) a collection of rules indicating actions that different actors (e.g., state, community) are expected to follow (e.g., compliance with quotas); and 3) procedures through which to make collective decisions. Ultimately, (Berkes et al. 1991; p.12) has argued that efforts to achieve these outcomes requires '…the sharing of power and responsibility between government and local resource users.'

It is difficult to trace the history of co-management. Plummer and Armitage (2007) document the evolution of the concept and note early examples of co-management practices in 19th century Spain, in the 1890s in Norway, as well as an early co-management agreement in 1901 in Japan. More recent examples of foundational co-management experience include the Bolt Decision in Washington State, USA, in the 1970s, numerous applications of co-management in Canada's Arctic starting from the late 1970s (Pinkerton 1989, Armitage et al. 2007), and the Gwaii Haanas Land-Sea-People plan which establishes a cooperative agreement between the Haida Nation and the federal government (ParksCanada 2018).

Co-management continues to evolve from an early focus on the resource toward a more integrated view of social and ecological systems. Moreover, a stronger focus on the complexity of social-ecological systems in the co-management literature has led to greater emphasis on learning through change, or adaptive co-management (Olsson et al. 2004).

The concept of co-management draws attention to numerous applied and policy-orientated attributes: 1) ensuring the engagement of a diversity of actors that are relevant, appropriate, and connected to the primary issues of concern; 2) creating an accessible process for deliberation and decision making in terms of space, timing, neutrality and the language used; 3) linking actors vertically (e.g., from national to local) and horizontally (e.g., across community-based organizations engaged in similar work); 4) recognizing that co-management is a long-term process and that there is ample evidence it takes a decade or more to actually develop; 5) highlighting the importance of learning (i.e., the shift to 'adaptive co-management') and the need to learn through complexity; and 6) encouraging the establishment of a legal foundation for co-management as opposed to voluntary notions of engagement (e.g., as is the case in northern Canada, where legally-recognized comprehensive land claims require co-management).

There remain both strengths and weaknesses with the concept of co-management both in theory and in practice. Overall, co-management tends to be more effective at smaller scales, and experience has highlighted the value of knowledge sharing and/or knowledge co-

production (e.g., conventional science and traditional knowledge) as a way to reflect diverse values and enhance the legitimacy of the decision-making outcomes. Despite these strengths, some challenges remain, and these should be further considered for better implementation of the concept. For example, more effort is needed to ensure that co-management processes are accessible to those most marginalised (e.g., an accessible and neutral location, and suitable time for discussions during the day, and language in which participants are comfortable communicating). In many instances, co-management would benefit significantly from being enshrined in a legal framework (e.g., as it is in northern Canada's land claim agreements) to ensure core principles are implemented.

Precautionary Approach (PA)

The Precautionary Approach calls for proactive measures to be taken where there is scientific uncertainty on the environmental impacts of proposed activities or use of the environment. While there are varied definitions of the precautionary approach with origins in German domestic law (Trouwborst 2002), the most commonly accepted wording has been in Principle 15 of the Rio Declaration (1992): "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". Essentially, the precautionary approach, or principle as it is also referred to (Trouwborst 2007), aims to ensure environmental protection through taking early actions and preventing environmental risks at an early stage, even when scientific uncertainties about the risks remain.

The notion of precaution thus provides critical guidance for making environmental decisions under uncertainty (Peel 2005). Due to the flexibility of its definition, the precautionary approach has found its way into international law and is widely incorporated into most international environmental agreements, from biodiversity, climate change, law of the sea, and biosafety (Freestone and Hey 1996). One of the first applications of PA was used in environmental protection of the North Sea in the 1980s (deFur and Kaszuba 2002), and it has since been incorporated into most international agreements and applied in fisheries management (Hilborn et al. 2001, González-Laxe 2005), ocean dumping, and nuclear testing (Wang 2011).

Yet, the flexibility of PA brings about uncertainty in the used terminology and raises concerns over the legal scope of the approach (Trouwborst 2007). Despite the simplicity of the notion of precaution, there has been much debate about the type and implementation of precautionary measures required by the approach (Sandin et al. 2002, Ellis 2006). The spectrum of available precautionary measures is under much discussion, with certain definitions of the approach calling for measures to be cost-efficient while others do not (Marr 2003). Another challenge is defining the level of 'serious harm' to the marine environment from human activities that triggers the need for precautionary measures (e.g. Levin et al. 2016). Yet, despite the ongoing discussion over the definitions and practical invocation of

the precautionary approach, precaution may be considered as one of the backbones of modern environmental governance (O'Riordan and Jordan 1995), calling upon a number of precautionary management measures (VanderZwaag 2002, VanderZwaag 2019).

Examples of the implementation of the PA: In 2009, the North Pacific Fishery Management Council in the USA implemented a new Fishery Management Plan for Fish Resources of the Arctic Management Area (2009 Arctic FMP) that closes federal waters of the U.S. Arctic from commercial fishing until scientific information is available on the fish stocks and ecosystem dynamics. The 1996 Protocol to the London Convention on Ocean Dumping fully embraces the notion of precaution and prohibits all dumping of wastes and other matter, except for those on a predefined list. The UN Sustainable Fisheries Resolution 61/105 (December 2006) and the International Guidelines for the Management of Deep-sea Fisheries on the High Seas (2008) call upon closing vulnerable marine ecosystems (VMEs), including seamounts, hydrothermal vents and cold water corals, to bottom-fishing until conservation and management measures have been established to prevent significant adverse impacts on VMEs.

Synthesis table:

CONCEPT	DEFINITION	SCOPE OF CONSIDERATION	APPLICATIONS TO DATE	PLACE IN MANAGEMENT, POLICY & REGULATIONS	SPACE FOR IMPROVEMENT
SES	Integrated complex systems that include social (human) and ecological (biophysical) subsystems in a two-way feedback relationship (Berkes 2011).	- Gives equal attention to the social and the ecological system and the interlinkages between them - Links with ecosystem services (Daily 1997, Partelow et al. 2016), resilience (Berkes 2011), and other environmental governance theories (Folke et al. 2005, Cox et al. 2016).	It has been used to evaluate community-based systems such as conflict and collaboration in situations such as: - irrigation systems (Hoogesteger 2015, McCord et al. 2016). - small-scale fisheries (Long et al. 2015, Blythe et al. 2017, Partelow et al. 2018).	Approach is not explicit in any policies or international agreement	- is a largely academic framework for analysis and comparison (Partelow 2018). - lack of a common analytical framework of SES poses significant challenges for the emerging field of SES (Schlüter et al. 2012, Colding et al. 2019). - a more precise definition is also warranted to avoid the risk of the

			- forestry (Fleischman et al. 2010, Oberlack et al. 2015, Davenport et al. 2016).		SES discourse becoming diluted (Marshall 2012).
EAM	Integrated adaptive management approach to help marine managers consider trade-offs to protect and sustain diverse and productive ecosystems and the services they provide. Informed by science, it incorporates the entire ecosystem, including humans, into management decisions (AORA 2019).	- Aims to balance human activities and environmental stewardship in a multiple-use context (Smith et al. 2017); - Has evolved to be fully inclusive of ecological, social, economic and governance considerations and inherently recognizes coupled social-ecological systems with stakeholders involved in an integrated and adaptive management process where decisions reflect societal choice.	- First implemented in the management of terrestrial parks (Grumbine 1994) - Started to be considered in the marine world during the 1990s, epitomized by Canada's Oceans Act, South Africa's Marine Living Resources Act and Australia's Ocean policy. - It was written into the common fisheries policy and has been implemented as the Marine Strategy Framework Directive (Europe) (ICES 2005, EU 2008).	- Is the focus of many marine-oriented organizations, such as ICES, PICES, FAO, UNEP, and NOAA (Link et al. 2014, Rudd et al. 2018). - The North Atlantic Ocean Research Alliance identified the following six benefits from EBM: (i) optimize benefits among a diverse set of societal goals; (ii) identify trade-offs and benefits among activities and resources within an ecosystem; (iii) understand the cumulative impacts of a management action beyond just a single issue; (iv) help communicate risks, uncertainties, and implications of management decisions; (v) ensure more transparent decision processes; (vi) science-based EBM approach will enhance collaboration, leverage opportunities, and improve decision-making (AORA 2019).	- Lack of knowledge - Conflicting interests - Lack of organizational/legal framework - Lack of communication (Marshak et al. 2016).
IM	Approach that links planning, decision-making and management arrangements across sectors in a unified framework, to enable a more comprehensive	- Encompasses the interconnectedness of natural systems, human systems and management (Bernal 2015). - Emphasizes practical management of multiple	- Integrated Management of the Australian NSW Marine Estate (Brooks et al. 2020); - Integrated management for the Barents Sea (Olsen et al. 2016);	- Is an aspiration of international agreements including the Law of the Sea Convention (UnitedNations 1995). - Is explicit in legislation in many jurisdictions:	It has been difficult to implement (Borja et al. 2008, Vince 2015) in a large part due to the complexities of existing management jurisdictions and arrangements (Stephenson et al. 2019, Stephenson et al. 2019).

	view of sustainability and the consideration of cumulative effects and trade-offs (Stephenson et al. 2019).	sectors to achieve diverse objectives - Brings together relevant actors from government, business, academia and civil society from the entire spectrum of ocean-related human activities (Winther et al. 2020).	- Integrated Management Plan for the North Sea; - Integrated Management of the Canadian North Pacific Coast: Marine Plan Partnership for the North Pacific Coast; - Canadian Beaufort Sea Integrated Management Plan and partnership.	- EU Water Framework Directive and Marine Strategy Framework Directive (ICES 2005, EU 2008). - Australian Oceans Policy (Vince 2012). - Canada's Oceans Act (Jessen 2011).	
MSP	A public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that have been specified through a political process (Douvere 2008).	- Recognizes the legal, political, economic, and ecological complexity of ocean governance (Ehler et al. 2009); - Should entail a cyclical and iterative approach incorporating new information over time and adapting its objectives and measures according to the evolution of the socio-ecological system.	- It was first stimulated by international and national interest in developing marine protected areas (MPAs), such as the Great Barrier Reef Marine Park (Australia) (Douvere 2008); - Currently, approximately 80 countries have implemented MSP in some form: - Belgium, Germany, the Netherlands, Norway, China, and Belize (which MSP covers the majority of the maritime space); - United States, Canada, and Croatia (where MSP is in place just for a particular area under national jurisdiction).	- Is being seen as a tool to manage the multiple uses of marine space, especially in areas where conflicts among users and the environment are already clear. - Has been recognized as a necessary tool to guarantee sustainable maritime development in the 2006 EU Green Paper (EU 2006); - Worldwide there are 22 countries in which MSP have been already approved by the government and are in place (Claus et al. 2017).	- A lack of integration of the social, cultural dynamics in the all MSP process (Gissi et al. 2018); - Often focusing more on specific sector objectives than on strategic priorities at the national level (Jones et al. 2016); - MSP case studies tend to be fragmented and develop in a practical way on an *ad hoc* basis (Jones et al. 2016); - Tend to be top down approaches and participatory platforms exist but are usually disconnected from executive decision making (Jones et al. 2016); - Lack of spatial representation of "social connections" with the marine environment; - Lack of economic estimates not from the market (Domínguez-Tejo et al. 2016);

					- Overall cultural/heritage values were poorly represented in comparison to economic and environmental values (Domínguez-Tejo et al. 2016).
PCM	- A system of rights and obligations for those with a shared interest or stake in a resource (e.g., fishery); - A collection of rules indicating actions that different actors (e.g., state, community) are expected to follow (e.g., compliance with quotas; - Procedures through which to make collective decisions (Osherenko 1998).	- Requires the sharing of power and responsibility between government and local resource users (Berkes et al. 1991); and draws attention to numerous applied and policy-orientated attributes: 1) Rnsuring the engagement of a diversity of actors that are relevant, appropriate, and connected to the primary issues of concern; 2) Creating an accessible process for deliberation and decision making in terms of space, timing, neutrality and the language used; 3) Linking actors vertically and horizontally; 4) Recognizing that co-management is a long-term process and that there is ample evidence it takes a decade or more to actually develop; 5) Highlighting the importance of learning and	- There are numerous descriptions of co-management in the literature, in wildlife, forests, parks and fisheries and ocean; - The Bolt Decision in Washington State, USA, in the 1970s; - Canada's Arctic starting from the late 1970s (Pinkerton 1989, Armitage et al. 2007); - The Gwaii Haanas Land-Sea-People plan which establishes a cooperative agreement between the Haida Nation and the federal government (ParksCanada 2018).	Tends to be more effective at a smaller scale, and experience has highlighted the value of knowledge sharing and/or knowledge co-production (e.g., conventional science and traditional knowledge) as a way to reflect diverse values and enhance legitimacy of the decision-making outcomes.	- More effort is needed to ensure that co-management processes are accessible to those most marginalized; - Co-management would benefit significantly from being enshrined in a legal framework to ensure core principles are implemented.

		the need to learn through complexity; 6) Encouraging the establishment of a legal foundation for co-management as opposed to voluntary notions of engagement.			
PA	In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.	- Calls for proactive measures to be taken where there is scientific uncertainty on the environmental impacts of proposed activities or use of the environment; - Aims to ensure environmental protection through taking early actions and preventing environmental risks at an early stage, even when scientific uncertainties about the risks remain (deFur et al. 2002); - Provides critical guidance for making environmental decisions under uncertainty (NPFMC 2009).	- Environmental protection of the North Sea in the 1980s (deFur et al. 2002); - The North Pacific Fishery Management Council in the USA in the new Fishery Management Plan for Fish Resources of the Arctic Management Area (NPFMC 2009); - The Protocol to the London Convention on ocean dumping (1996); - UN Sustainable Fisheries Resolution 61/105 in December 2006 and the International Guidelines for the Management of Deep-sea Fisheries on the High Seas (2008).	- It has found its way into international law and is widely incorporated into most international environmental agreements, from biodiversity, climate change, law of the sea, biosafety (Freestone et al. 1996), fisheries management (Hilborn et al. 2001, González-Laxe 2005), ocean dumping, and nuclear testing (Wang 2011).	- Uncertainty in the used terminology and raises concerns over the legal scope of the approach (Ellis 2006); - There has been much debate about the type and implementation of precautionary measures required by the approach (Sandin et al. 2002, Ellis 2006); - Lack of definition of the level of 'serious harm' to the marine environment from human activities that triggers the need for precautionary measures (Levin et al. 2018).

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