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Key principles of marine ecosystem-based management

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ABSTRACT

Ecosystem-Based Management (EBM) has gained international popularity in recent years, but the lack of consensus on its definition has precluded the use of a universal implementation framework. The large number and variety of principles that make up EBM, and the diversity in perspectives among key management players, has impeded the practical application of EBM. Agreement on a list of the essential ingredients of EBM is vital to successful application. A frequency analysis of EBM principles was conducted to identify the Key Principles that currently define EBM, from a list of twenty-six principles extracted from a subset of the EBM theoretical/conceptual literature (covering a range of published sources across disciplines and application types). Fifteen Key Principles were identified (in descending frequency of appearance in the literature): **Consider Ecosystem Connections**, **Appropriate Spatial & Temporal Scales**, **Adaptive Management**, **Use of Scientific Knowledge**, **Integrated Management**, **Stakeholder Involvement**, **Account for Dynamic Nature of Ecosystems**, **Ecological Integrity & Biodiversity**, **Sustainability**, **Recognise Coupled Social-Ecological Systems**, **Decisions reflect Societal Choice**, **Distinct Boundaries**, **Interdisciplinarity**, **Appropriate Monitoring**, and **Acknowledge Uncertainty**. This paper also examines the development of EBM principles over time, leading to predictions on the directions EBM will take in the future. The frequency analysis methodology used here can be replicated to update the Key Principles of EBM in the future. Indeed, further research on potential emerging Key Principles such as 'Consider Cumulative Impacts', 'Apply the Precautionary Approach' and 'Explicitly Acknowledge Trade Offs' will help shape EBM and its successful application in the management of marine activities.

1. Introduction

There is no debate surrounding the intrinsic value of global marine ecosystems [1,2] or the immense pressures humans have inflicted on them [2–4]. With rapid population growth and densely inhabited coastal areas, our dependence on marine resources is greater than ever [5]. The overuse and mismanagement of ecosystem services – e.g., through overexploitation, habitat loss and pollution – have placed great pressure on marine systems [4–6], thereby threatening the future of marine ecosystems, and the services they provide [5,6].

Traditional silo-structured management, focusing on a single species or sector, is widely seen as insufficient [7,8]. It has failed to protect marine systems from human pressures [5] or fishery stock collapses [9,10] and in turn these failures have deeply impacted the humans that depend on these resources [2,11]. The consequences of ineffective conventional management systems, along with the desire to restore and maintain ecosystem health, have induced a desire for change. Thus, while there is not always agreement on the exact direction management should take, there is a general consensus on the need for improvement in conventional management practices.

The third point of broad consensus relates to some of the goals of the change toward new management approaches, specifically to better acknowledge and incorporate aspects such as biodiversity, the complexity of social-ecological systems, the need for stakeholder participation and the appropriate use of incentives (e.g. [12]). These considerations are reflected to some extent in the widely-accepted shift to the more holistic approach known as Ecosystem-Based Management (EBM), generally seen not as a strategy that manages the ecosystems themselves, but rather one that manages the human activities that have an impact on ecosystems, and takes these effects into account when making management decisions [13].

However, consensus breaks down when it comes to the details of what principles should be included within EBM. There are wide variations in the definitions of EBM, and in the environments or

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sectors to which it can be applied, leaving EBM without a universal application framework [14]. As a result, EBM implementation is taking place in many different forms with various combinations of principles. In particular, the respective emphasis placed on ecological, social, and governance factors [14] will depend on the EBM principles utilized, the degree to which each are applied, as well as the overarching objectives of the organization implementing EBM [15]. For example, the Food and Agriculture Organization of the United Nations' (FAO) Ecosystem Approach to Fisheries, which focuses on balancing ecological, governance and socio-economic factors [14], differs from that adopted by various government and nongovernmental organizations, e.g., Greenpeace's Ecosystem Approach which emphasizes ecological factors [16].

Faced with this fundamental difference in thinking on the Key Principles of EBM, the objective of this paper is, first, to provide a clear and up-to-date list of these Key Principles, derived from publications, and second, to consider implications for the future of EBM. It is hoped that this analysis will improve links between theory and practice of EBM, allowing more consistent applications to marine activities.

The research presented here contributes to building consensus relating to the Key Principles required within an EBM framework. This involves a brief review of the historical development of EBM and a systematic analysis of theoretical literature concerning EBM, which enables specification of a credible subset of recent publications, leading to development of a set of the crucial 'Key Principles' required to successfully implement EBM. This is accompanied by an analysis of the development of EBM principles over time, to identify which established principles have diminished in their acceptance as defining characteristics in the literature, and on the other hand, which more contemporary principles exhibit potential to become Key Principles in the future. Finally, principles put forth in two early syntheses by Holt and Talbot [17] and Mangel et al. [18] are compared with those prevalent in the EBM literature today. Although the principles from these works receive relatively little recognition in current marine EBM discussions, they provide a historical reference point and allow for the identification of EBM principles that may be under-emphasized today.

2. Background

2.1. What is EBM?

There is no single agreed-upon definition for EBM (also referred to as the Ecosystem Approach); these terms have been defined in many different ways to date. A typical definition of EBM acknowledges the complexity and interspecies relationship within ecological systems, but many also account for social and governance objectives, with the latter aspects broadening the range of definitions. On the one hand, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), for example, has a narrow set of ecological objectives, describing the ecosystem approach as management that:

> "*takes into account all the delicate and complex relationships between organisms (of all sizes) and physical processes (such as currents and sea temperature) that constitute the Antarctic marine ecosystem*" [19].

On the other hand, the United Nations Convention on Biological Diversity (CBD) integrates ecological, social and governance objectives, describing the ecosystem approach as:

> *"a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way"* [20].

The Communications Partnership for Science and the Sea (COMPASS) published a more in-depth, inclusive definition developed by over two hundred science and policy experts in the United States. EBM was defined there as:

> "*an integrated approach to management that considers the entire ecosystem, including humans. The goal of EBM is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. EBM differs from current approaches that usually focus on a single species, sector or activity or concern; it considers the cumulative impacts of different sectors*" [21].

EBM has recently gained momentum in marine management initiatives [22] and increasing attention in the fisheries sector. EBM syntheses include Sinclair and Valdimarsoon [23] *Responsible Fisheries in the Marine Ecosystem,* Christensen and Maclean [24] *Ecosystem Approaches to Fisheries: A Global Perspective* and Link's [25] *Ecosystem-Based Fisheries Management: Confronting Tradeoffs.* The importance of considering human dimensions in marine EBM has been highlighted [26].

The rise in popularity of EBM has led to sector-specific variations, such as the Ecosystem Approach to Fisheries [27]. Each version of EBM has differing underlying principles (with some also providing frameworks for their implementation) and no single approach currently dominates the field of natural resource management [14]. Among academics, government agencies and NGOs, EBM has been defined in a variety of contexts (e.g. including general, terrestrial versus marine applications) as well as sectors such as forestry and the fishing industry.

2.2. A brief history of EBM principles

Despite EBM's more recent popularity, the philosophies behind it are far from new and in some areas have been practised by indigenous peoples for over ten thousand years [28]. Although not widely recognized, one of the first major initiatives to include overall ecosystem health in principles of natural resource management was in the 1970s [29], during a set of workshops on wildlife management attended by professionals across North America from a wide range of disciplines and organizations [17]. Indeed, prior to that point in time the term EBM does not seem to have appeared widely in the literature. The list of four management principles developed at the workshop, entitled *New Principles for the Conservation of Wild Living Resources* [17] went on to gain international recognition in 1978 when they were utilized at the United Nations Conference on the Law of the Sea (UNCLOS) and therefore contributed to a major stepping-stone in marine policy [29].

The four principles are as follows:

1. *The ecosystem should be maintained in a desirable state such that*
   a. *consumptive and non-consumptive values could be maximized on a continuing basis,*
   b. *present and future options are ensured, and*
   c. *risk of irreversible change or long-term adverse effects as a result of use is minimized.*
2. *Management decisions should include a safety factor to allow for the facts that knowledge is limited and institutions are imperfect.*
3. *Measures to conserve a wild living resource should be formulated and applied so as to avoid wasteful use of other resources.*
4. *Survey or monitoring, analysis, and assessment should precede planned use and accompany actual use of wild living resources. The results should be made available promptly for critical public review* [17].

These principles focused on ecological objectives, as at this time "resource conservation was regarded primarily as a biological

problem" [18], but they nonetheless provided the foundation for EBM approaches, which also acknowledged social and governance objectives.

In 1996, Mangel et al. [18] sought to update these principles and take into account some of the more contemporary management issues and applications. Several meetings with scientists and managers were held across the globe between 1992 and 1994, culminating in a final workshop to incorporate international perspectives on the seven management principles, with implementation mechanisms for each, that were developed and later published as the *Principles for the Conservation of Wild Living Resources* [18]. The seven principles are as follows:

> *"Principle I. Maintenance of healthy populations of wild living resources in perpetuity is inconsistent with unlimited growth of human consumption of and demand for those resources*
> *Principle II. The goal of conservation should be to secure present and future options by maintaining biological diversity at genetic, species, population, and ecosystem levels; as a general rule neither the resource nor other components of the ecosystem should be perturbed beyond natural boundaries of variation*
> *Principle III. Assessment of the possible ecological and sociological effects of resource use should precede both proposed use and proposed restriction or expansion of ongoing use of a resource*
> *Principle IV. Regulation of the use of living resources must be based on understanding the structure and dynamics of the ecosystem of which the resource is a part and must take into account the ecological and sociological influences that directly and indirectly affect resource use*
> *Principle V. The full range of knowledge and skills from the natural and social sciences must be brought to bear on conservation problems*
> *Principle VI. Effective conservation requires understanding and taking account of the motives, interests, and values of all users and stakeholders, but not simply averaging their positions*
> *Principle VII. Effective conservation requires communication the is interactive reciprocal, and continuous"* [18]

Although the principles described by both Holt and Talbot [17] and Mangel et al. [18] are not labeled explicitly as EBM, they both exhibit innovative EBM philosophies for their time, and mark the beginning of clear principles to describe this holistic management process.

2.3. Gaps between EBM theory and practice

The above history of the development of EBM principles demonstrates that the idea of such principles is not new, but even today there is much still to be learned before EBM becomes widely implemented in marine systems. The overwhelming variety of terminology and definitions for EBM creates confusion and results in differing perspectives on how EBM should be implemented in a marine management context. This also makes it difficult to begin the EBM process and choose an approach which is most appropriate for a given area or environment. The lack of consensus on what constitutes the key EBM principles creates a gap between theory and practice, and impedes successful application.

3. Methodology

3.1. The Key Principles of EBM

3.1.1. Selection of EBM literature

To assess the state of published materials on EBM principles, an extensive literature search was conducted, covering academic, government and NGO sources across a wide range of EBM applications, including applications in terrestrial environments, marine settings and sector-specific approaches such as fisheries, forestry and agriculture. A subset of these EBM sources was selected for further analysis using three selection criteria: (1) articles to be included must define EBM through a clear list of EBM principles, (2) articles must take a relatively broad and inclusive perspective of EBM (as discussed above), acknowledging interconnections among ecological, social and governance systems, and (3) articles (and/or their authors) must be widely accepted as leading publications (or people) in the field and/or (in the case of authors) having experience in practically applying EBM. The latter criterion was assessed based on factors such as the number of articles published by the author on the topic, the frequency of citations for the article, and whether a successful case study was utilized in the publication.

While hundreds of EBM publications were analyzed (with a cut-off in publication date of Spring 2010), only thirteen publications satisfied the criteria described above, and thus were selected for further analysis. These publications were from the primary literature, technical reports and guidelines from academia, government, international organizations, and NGOs. The thirteen selected articles varied in EBM application, including those oriented towards general implementation, those focusing on terrestrial or marine environments, as well as those taking a sector-specific approach for the forestry and fishing industries. No publications that satisfied these three criteria were found in the agriculture sector.

The thirteen articles are organized for this analysis according to their application area (general, terrestrial or marine). Note that some of the selected publications listed as having a terrestrial focus in fact do not specify a medium of application and resemble general applications, but the focus in the terrestrial environment is deduced from the article's publication or frequent citation in terrestrially-oriented journals. Similarly some publications discuss EBM in a marine environment, and are published in marine journals or use marine-based case studies, but do not limit their analyses of EBM solely to marine applications. See Table 1 for a list of the publications that make up the selected literature used for further analysis, along with background information on each source.

3.1.2. Defining EBM principles

The EBM principles along with their respective definitions were extracted from each publication and compiled. As with the terminology of EBM itself, there are many similar terms and various accepted definitions for each EBM principle. To avoid repetition or overlapping terms during the analysis, principles from different publications that were sufficiently similar were grouped together. An appropriate name for that consolidated EBM principle was assigned to each group of similar terms, and each resulting EBM principle was defined through a consolidation of the various definitions from corresponding sources, to ensure that the resulting definition satisfied all the interpretations of the term. There were wide variations across the set of publications in both the number of EBM principles and the detail with which they are described; accordingly, the description of each EBM principle was carefully reviewed. This methodology led to a comprehensive list of twenty-six EBM principles, along with their consolidated definitions, being extracted from the selected publications.

3.1.3. Identification of the Key Principles of EBM

Frequency analyses were conducted of (a) the number of EBM principles that appeared in each of the selected publications, and (b) conversely, for each principle, the number of publications in which it appeared. We define 'Key Principles' of EBM (those necessary for

Table 1
Background information on the list of selected publications analyzed to derive a list of 'Key Principles' that currently define EBM.

Application Type	Publication	Background Information
General applications	CBD (2000)	In 2000 United Nations Convention on Biological Diversity (**CBD**) developed 12 Principles of the Ecosystem Approach [25] that cater to a variety of disciplines and approaches around the world [34] and are widely cited and utilized in EBM literature [35].
	EBM Tools (2010)	**EBM Tools** [36] is an alliance made up of a long list of users, providers and researchers promoting the implementation of EBM in aquatic, marine and terrestrial environments. Their *Road Map of the Core Elements of EBM* was developed by COMPASS and gives a theoretical perspective of EBM provided by those who practically apply it.
Terrestrial Focus	Grumbine (1994)	**Grumbine's** [37] list of EBM principles in *What is Ecosystem Management?* is widely accepted and has been cited in over 1130 journal articles. This publication was the most dated publication selected. Evidence of a terrestrial focus includes the article's use of EBM definitions from the forestry sector to determine the list of fundamental components.
	Christensen (1996)	**Christensen *et al.*'s** [38] list of principles in *Ecological Applications* has also been widely cited in over 870 related articles. This article also did not specify a medium of application, yet it arose often in the literature review for the terrestrial field [39].
	Lackey (1998)	**Lackey's** [40] *Seven Pillars of Ecosystem Management*, has been cited in approximately 140 publications, despite the general focus of this article, it is published in the journal *Landscape and Urban Planning*, indicating a terrestrial focus.
	NRC (2008)	**Natural Resources Canada's (NRC)** [41] support and use of EBM in the forestry sector is expressed in *Implementing Ecosystem-based Management Approaches in Canada's Forests: A Science Policy Dialog.*
Marine focus	Arkema (2006)	**Arkema *et al.*** [42] utilize EBM definitions from various publications (in a manner similar to Grumbine [37]), to develop a list of EBM core elements, applied to marine cases. However, the publications that are used to formulate this list include EBM publications geared towards both terrestrial and marine applications, giving this a broader applicability. This article is widely used and has been cited in 75 publications.
	Boesch (2006)	**Boesch** [43] provides an analysis of the application of key EBM principles in the restoration of Chesapeake Bay and Coastal Louisiana – even though the principles themselves are not specific to a marine environment.
	Forst (2009)	In **Forst** [33] contemporary themes of EBM were utilized and an analysis of the convergence of integrated coastal zone management implied a marine focus in its analysis and in its study of the Great Barrier Reef Marine Park and Belize Marine Protected Area Program.
	NOAA [44]	As a result of the **National Oceanic and Atmospheric Administration's (NOAA)** contributions to ocean science and management their ecosystem approach [44] was considered appropriate for inclusion in the set of publications selected for further analysis.
	McLeod [45]	**McLeod and Leslie's** [45] book *Ecosystem-based Management for the Oceans* focuses on EBM in a marine setting, touching on theory, practical application and a variety of successful case studies.
	FAO (2001)	In 2002 **FAO** adopted the Ecosystem Approach to Fisheries [46], which is widely used and respected around the world, in research fields as well as within NGOs. The definition of **FAO's** Ecosystem Approach to Fisheries described in Bianchi [9] was used for this analysis.
	WWF [47]	**World Wildlife Fund's (WWF)** publication *Policy proposals and operational guidance for ecosystem-based management of marine capture fisheries* [47] states their version of the defining elements of EBM in the fisheries sector which has been utilized in the academic evaluation of the global implementation of EBM in fisheries [48].

the successful practical application of EBM) as those principles that appear in the majority of the selected publications.

3.2. Dynamics of EBM principles

Through an examination of publication dates, an analysis was undertaken of how the frequency of appearance of each EBM principle changed over time. For infrequently-occurring EBM principles (those not concluded to be Key Principles based on the definition above), the date of the first and last publication (among the thirteen articles) that referred to that principle were recorded to investigate if these infrequent principles have either (a) declined in popularity over time or (b) are growing in popularity and thus may be predicted to become Key Principles in the future. Specifically, EBM principles that were present in earlier publications but absent from more recent publications may no longer be associated with or used to define EBM, while EBM principles that first appeared only in more recent publications may be 'infrequent' only because they are newly associated with EBM and may become Key Principles in the future.

The presence of EBM principles and Key Principles derived from the selected publications were contrasted with those present in the principles put forth in the historical publications by Holt and Talbot [17] and Mangel et al. [18].

4. Results

4.1. Key Principles of EBM

Twenty-six principles of EBM were identified (Table 2). Of the twenty-six principles of EBM identified from the literature, those EBM principles present in 50% or more of the thirteen selected publications (i.e. having a frequency of 7 or greater) were defined as the Key Principles of EBM. These are considered fundamental for its successful application, as indicated by their relatively widespread recognition in creditable and contemporary EBM publications.

Analysis of the data indicated a natural break in the frequencies of the 26 EBM principles, as there were none with frequencies of 6 or 7 (See Table 2). Fifteen principles (discussed below), with frequencies of 8 or more, are therefore Key Principles of EBM. These will be emphasized in bold for the remainder of the paper, with all other EBM principles shown in quotations. The three Key Principles that were most frequently acknowledged in the literature (11 of 13 publications) were **Consider Ecosystem Connections**, **Appropriate Spatial & Temporal Scales** and **Adaptive Management**. The **Use of Scientific Knowledge** follows with a frequency of 10, and both **Stakeholder Involvement** and **Integrated Management** with a frequency of 9. The remaining 9 Key Principles listed below all have a frequency of 8 out of a possible 13: **Sustainability**, **Account for Dynamic Nature of Ecosystems**, **Ecological Integrity & Biodiversity**, **Recognise Coupled Social-Ecological Systems**, **Decisions reflecting Societal Choice**, **Distinct Boundaries**, **Interdisciplinarity**, **Appropriate Monitoring** and **Acknowledge Uncertainty**.

4.2. Dynamics of EBM principles

4.2.1. Development of EBM principles within the selected publications

The fifteen Key Principles of EBM were for the most part present consistently across the selected EBM publications from 1994 to 2010, and all had appeared in at least one of the selected

Table 2
A frequency analysis of the EBM principles within the different environmental or sector specializations derived from the selected publications. The EBM principles that were most frequently acknowledged in the literature, and therefore referred to here as Key Principles, are shaded in gray.

Application Type:	**General**		**Terrestrial**				**Marine**							**Frequency**
Sector Specific Application Type:						**Forestry**						**Fisheries**		**Total**
Publication:	**CBD**	**EBM Tools**	**Grumbine**	**Christensen**	**Lackey**	**NRC**	**Arkema**	**Boesch**	**Forst**	**NOAA**	**McLeod**	**FAO**	**WWF**	
EBM Principles Year:	**2000**	**2010**	**1994**	**1996**	**1998**	**2008**	**2006**	**2006**	**2009**	**2007**	**2009**	**2001**	**2002**	
Consider Ecosystem Connections	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	**11**
Appropriate Spatial & Temporal Scales	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		**11**
Adaptive Management	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	**11**
Use of Scientific Knowledge	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓	**10**
Stakeholder Involvement	✓			✓		✓	✓	✓	✓	✓		✓	✓	**9**
Integrated Management	✓	✓	✓			✓	✓	✓		✓	✓	✓		**9**
Sustainability	✓	✓		✓	✓		✓	✓			✓	✓		**8**
Account for Dynamic Nature of Ecosystems	✓	✓		✓	✓			✓		✓		✓	✓	**8**
Ecological Integrity & Biodiversity	✓				✓		✓	✓	✓	✓		✓	✓	**8**
Recognise Coupled Social-Ecological systems		✓	✓	✓	✓	✓	✓	✓			✓			**8**
Decisions reflect Societal Choice	✓	✓	✓		✓		✓			✓	✓		✓	**8**
Distinct Boundaries		✓	✓		✓	✓	✓		✓	✓	✓			**8**
Interdisciplinarity	✓	✓				✓	✓	✓	✓	✓	✓			**8**
Appropriate Monitoring		✓	✓	✓			✓	✓	✓		✓		✓	**8**
Acknowledge Uncertainty	✓		✓	✓			✓	✓	✓	✓		✓		**8**
Acknowledge Ecosystem Resilience	✓			✓	✓			✓			✓			**5**
Consider Economic Context	✓	✓				✓	✓							**4**
Apply the Precautionary Approach							✓	✓	✓			✓		**4**
Consider Cumulative Impacts		✓								✓	✓			**3**
Organizational Change			✓			✓		✓						**3**
Explicitly Acknowledge Trade Offs		✓				✓					✓			**3**
Consider Effects on Adjacent Ecosystems	✓									✓				**2**
Commit to Principles of Equity	✓											✓		**2**
Develop Long Term Objectives	✓			✓										**2**
Use of All Forms of Knowledge	✓													**1**
Use of Incentives												✓		**1**
Total Number of EBM Principles	18	15	11	12	9	9	16	16	10	13	13	13	8	

publications by the year 2000 (See Table 2). Ten of the Key Principles were present in the earliest selected publication in 1994, Grumbine's [30] *What is Ecosystem Management?*: **Consider Ecosystem Connections**, **Appropriate Spatial & Temporal Scales**, **Recognise Coupled Social-Ecological Systems**, **Decisions reflect Societal Choice**, **Adaptive Management**, **Use of Scientific Knowledge**, **Integrated Management**, **Distinct Boundaries**, **Appropriate Monitoring**, **Acknowledge Uncertainty**. **Sustainability**, **Stakeholder Involvement** and **Account for Dynamic Nature of Ecosystems** were first seen, among the selected publications, in 1996 in Christensen's [31] article published in Ecological Applications. The Key Principles **Ecological Integrity & Biodiversity** and **Interdisciplinarity** first appeared in 1998 in Lackey's [32] *Seven Pillars of Ecosystem Management* and in 2000 in the CBD's [20] *Ecosystem Approach* respectively.

The more infrequently-noted principles break into three groupings. First, there were 3 EBM principles that appeared predominantly in more recent publications. 'Consider Cumulative Impacts' appears in only 3 of the thirteen articles, all of which were published after 2007 (with 2 of these having a marine focus and 1 a general application). 'Apply the Precautionary Approach', present in 4 of the 13 publications, only first appeared in this set of literature in 2001. 'Explicitly Acknowledge Trade Offs' was present in 3 of the selected publications, all appearing after 2008 (covering general, marine and terrestrial applications). Second, 'Acknowledge Ecosystem Resilience' and 'Consider Economic Context' were evenly represented throughout the timeframe of the publications in all 3 application types, but are not Key Principles as they only had frequencies of 5 and 4 respectively. Third, four principles seem to have diminished in interest over time. 'Develop Long Term Objectives' and 'Commit to Principles of Equity' were only present in 2 of the publications, appearing before 2000 and 2001 respectively, while 'Use of Incentives' and 'Use of All forms of Knowledge' were only used in a single publication each, in 2000 and 2001 respectively.

4.2.2. *Contemporary EBM principles vs. historical principles*

Each of Holt and Talbot's [17] 4 principles listed above are extensive and therefore encompassing multiple Key Principles concluded in this paper in each of their principles. Within Holt and Talbot's [17] principles, there were 9 of what we consider Key Principles present: **Sustainability**, **Consider Ecosystem Connections**, **Appropriate Spatial & Temporal Scales**, **Account for Dynamic Nature of Ecosystems**, **Ecological Integrity & Biodiversity**, **Adaptive Management**, **Use of Scientific Knowledge**, **Appropriate Monitoring** and **Acknowledge Uncertainty**. The lower-ranking EBM principles 'Acknowledge Ecosystem Resilience',

'Consider Economic Context' and 'Apply the Precautionary Approach' were also recognized along with 2 principles not found in our selected literature: 'Conservation of all Resources' and 'Critical Public Review of Results'. There were 10 Key Principles within Mangel et al.'s [18] list of 7 principles: **Sustainability**, **Consider Ecosystem Connection**, **Account for Dynamic Nature of Ecosystems**, **Ecological Integrity & Biodiversity**, **Recognise Coupled Social-Ecological Systems**, **Decisions reflect Societal Choice**, **Use of Scientific Knowledge**, **Stakeholder Involvement**, **Interdisciplinarity** and **Appropriate Monitoring**. Mangel et al. [18] also recognized 2 lower-ranking EBM principles 'Use of All Forms of Knowledge' and 'Consider Economic Context' as well as an additional principle 'Communication', which was not present as an EBM principle in the selected publications.

5. Discussion

5.1. Key Principles of EBM

The thirteen publications examined in this article represent a relatively rare group, in that they each explicitly provide a set of core or 'defining' EBM principles (albeit expressed in varying ways, and with varying detail).

It should be noted that the absence of a certain principle within the list of principles given by one of the thirteen publications does not imply that the author feels it is unimportant. However, this does indicate that it was not felt to have been a priority as a defining characteristic of EBM, at the point in time the article was written.

None of the publications contained a complete list of the 15 Key Principles that arose from the collective analysis of all publications. However, it is remarkable that Arkema et al. [33] provided a list of principles that contained 14 of the 15 Key Principles, only missing the **Account for Dynamic Nature of Ecosystems**. The completeness of this list may be a result of their methodology, since Arkema et al. [33] completed a frequency analysis of keywords used in the definition of EBM published within 18 peer reviewed academic journals (though unlike the present article, this was not specific to publications using EBM principles). Their use of keywords from a wide range of publications provided a solid foundation to develop their list of up-to-date principles. Almost as complete are the lists of Boesch [34], which included 13 of the 15 Key Principles (all but **Decisions reflect Societal Choice** and **Distinct Boundaries**), as well as EBM Tools [35] and CBD's Ecosystem Approach [20], with these containing all but 3 the 15 Key Principles (missing **Ecological Integrity & Biodiversity**, **Stakeholder Involvement** and **Acknowledge Uncertainty**, and **Recognise Coupled Social-Ecological Systems**, **Distinct Boundaries** and **Appropriate Monitoring** respectively).

5.2. Dynamics of EBM principles

5.2.1. Key Principles and other principles

It is clear that EBM is an evolving concept and the Key Principles presented in this paper represent the development of EBM to date. As current management practices are analyzed and further research progresses, EBM will continue to develop. Analyzing the change which EBM principles have already undergone helps pinpoint those EBM principles that have declined in support or have been replaced, as well as principles that are 'up and coming' and which accordingly may reflect the future direction of EBM.

The insight and expertise within the field of EBM that was used to determine the 15 Key Principles of EBM in this article arose over the 16-year publication period, 1994–2010, of the selected publications. Since most of the Key Principles were present in at least one of the 2 earliest publications (in 1994 and 1996), it is likely that these Key Principles were also associated with EBM prior to 1994. Further, the emergence of these principles over this time, albeit within our small set of selected publications, gives an indication of when each principle appeared and whether it grew or declined in prominence as a defining principle of EBM. This information will help to predict the direction EBM may take in the future.

Examining the lower-frequency EBM principles present in the more recent selected publications indicates that some of these, while newer to the field of EBM, could potentially emerge as Key Principles of EBM in the future. These include 'Consider Cumulative Impacts', 'Apply the Precautionary Approach' and 'Explicitly Acknowledge Trade Offs', all of which may be newly associated with EBM, but are far from new concepts in the field of natural resource management. The first 2 of these appeared particularly in marine publication (See Table 2), perhaps suggesting their particular relevance in the marine environment.

Several EBM principles had low frequencies in the early selected literature and did not resurface in more recent publications. For example 'Develop Long Term Objectives' and 'Commit to Principles of Equity' were only present in 2 of the publications before 2000 and 2001 respectively. Similarly 'Use of Incentives' and 'Use of All Forms of Knowledge' were only acknowledged in a single publication in 2000 and 2001 respectively. On the other hand, each of these EBM principles did appear specifically in FAO's Ecosystem Approach to Fisheries [14] and/or CBD's [20] Ecosystem Approach, which are both widely accepted publications. Why the more recent of the selected publications would have such significant differences with these prominent international bodies in terms of exclusion of the above EBM principles is an interesting question. The result may reflect explicit differences in the fisheries of interest (e.g., with the FAO and CBD including principles relevant to fisheries of developing nations and small-scale applications) or an unintended gap in the analysis within the theoretical literature. Indeed, although these EBM principles are not highly recognized in the theoretical literature, they may be more prevalent in practical marine management.

5.2.2. Future implications from historical EBM principles

A long and diverse list of professionals, from academic, government and nongovernment organizations and covering multiple resource sectors, participated in the development of the principles in both the Holt and Talbot [17] and Mangel et al. [18] publications. Although both sets of principles were published decades ago, the participation therein of prominent individuals [17] suggest these publications can be usefully compared to current EBM Key Principles, providing insights into the future of EBM.

From the 4 principles and their descriptions in Holt and Talbot [17], it was clear that ecological objectives dominated management goals in this publication. Although **Sustainability** is present, the publication lacks EBM principles that acknowledge social objectives, while including many ecologically focused Key Principles along with the EBM principle 'Acknowledge Ecosystem Resilience'. Holt and Talbot [17] also offered insightful Key Principles relating to governance, along with 'Consider Economic Context' and the 'Apply the Precautionary Approach' (the latter being an innovative inclusion at that time). Holt and Talbot [17] also put forth 2 interesting principles relevant to current management problems that were not present in the list of EBM principles derived from the selected literature:

- 'Conservation of all Resources' touched upon the importance of not wasting resources, such as bycatch, capital, labor and fuel, while trying to extract the commercial/desired resource. This issue is particularly relevant to the fishing industry [36]. The re-examination of this principle within the field of EBM or

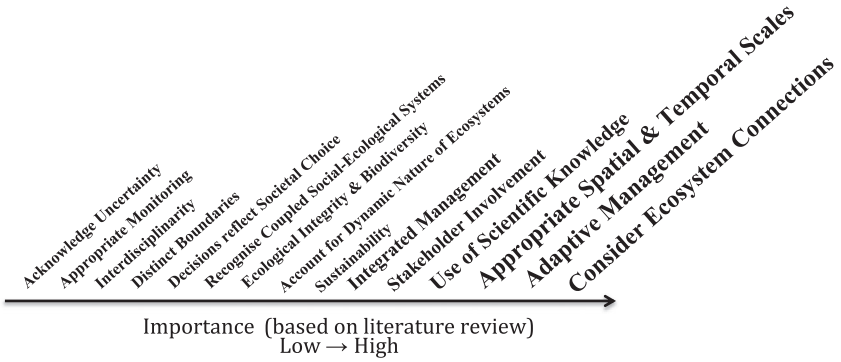

Fig. 1. Key EBM Principles listed in increasing frequency of importance according to the literature, with larger font indicating greater importance.

particularly in the sector-specific approaches in the fishing industry may help EBM tailor to specific fishery management issues.

- 'Critical Public Review of Results' highlights the importance of accountability in natural resource management. Open lines of communication and transparency regarding management actions and initiatives are currently recognized as crucial for achieving sustainable fisheries management [37,38]. 'Critical Public Review of Results' provides the medium for the public to be aware of management actions and is a stepping-stone to further explore social objectives.

Mangel et al. [18] included 7 principles to update those published by Holt and Talbot [17] and include social objectives to acknowledge contemporary management issues. It is evident that including social factors was a primary objective in revising Holt and Talbot's principles: the Key Principles with social objectives, determined in this article, were all present, as was the use of 'Use of All Forms of Knowledge' in management. This emphasis on social objectives shifted the focus, so that some of the ecological and governance principles that were supported by Holt and Talbot were not present. Indeed, although Mangel et al. [18] did include some ecologically focused Key Principles, **Appropriate Spatial & Temporal Scale** was not highlighted, nor was the principle of 'Ecosystem Resilience'. Similar to Holt and Talbot [17], Mangel et al. [18] did not include any of the governance objectives from the set of Key Principles of EBM deduced in this paper. Although both recognized the importance of **Use of Scientific Knowledge** and **Appropriate Monitoring**, Mangel et al. [18] did not include Key Principles such as **Adaptive Management** and **Acknowledge Uncertainty** nor was there the 'Precautionary Approach' (one of the potentially emerging Key Principles in this article). Yet Mangel et al. [18] did advance towards a contemporary approach by acknowledging that EBM management should have an **Interdisciplinarity** focus, and introduced the principle of 'Communication', which is now widely accepted, much like Holt and Talbot's [17] 'Critical Public Review of Results.'

Comparing the Key Principles to those put forth by Holt and Talbot [17] and Mangel et al. [18] confirms that EBM has developed over time. These principles have provided a benchmark to assess how far EBM has come as well as a reference point to look back and reflect on whether previously prominent principles have been lost or superseded. By gaining a better understanding of EBM principles over time this enables the development of a comprehensive up-to date definition of EBM, resolving the confusion surrounding the term and helping to close the gap between EBM theory and practice.

6. Conclusion

Ecosystem-based Management (EBM) has been a prominent topic in the environmental, landscape/seascape and natural resource management fields for decades. However, there remains a lack of consensus on what defines EBM, and on its Key Principles, that continues to impede the implementation process, and delays solutions to some of the major challenges associated with its application in a marine setting [39]. This paper attempts to break that cycle through a process for systematically selecting major EBM publications that explicitly propose sets of EBM principles, then synthesizing across these sets, to develop a clear and concise list of Key Principles that currently define EBM, and that may be seen as necessary for its successful application. The analysis produced 13 publications, out of the extensive theoretical/conceptual literature base, each providing an inclusive definition of EBM broken down into its parts or principles. From these, a synthesis process led to a comprehensive list of 26 EBM principles, of which 15 appeared frequently enough to be deemed Key Principles of EBM (See Fig. 1).

This paper also tracked the development of EBM principles over time, based on their appearance among the selected publications, exploring the rationale for change and predicting the directions that EBM may take in the future. A comparison was also made with Holt and Talbot's [17] wildlife conservation principles and their revisions by Mangel et al. [18]. From this analysis it is clear that EBM is an evolving concept; the list of Key Principles produced here was based on the expertise reflected in past EBM research and applications, and in turn solidifies the definition and representation of EBM at the present time. The Key Principles determined here enabled and contributed to the development of an up-to-date definition of EBM – see below.

6.1. Ecosystem-based management – A definition

Ecosystem-based management is an interdisciplinary approach that balances ecological, social and governance principles at appropriate temporal and spatial scales in a distinct geographical area to achieve sustainable resource use. Scientific knowledge and effective monitoring are used to acknowledge the connections, integrity and biodiversity within an ecosystem along with its dynamic nature and associated uncertainties. EBM recognizes coupled social-ecological systems with stakeholders involved in an integrated and adaptive management process where decisions reflect societal choice.

While change is inevitable, and the principles underlying EBM will continue to develop, this is no justification to delay the implementation of EBM. Indeed, the frequency analysis

methodology used in this paper, by drawing on expertise from a wide range of sources and application types to combine the EBM expertise from various fields, can be re-applied periodically in the future, incorporating new literature to update the set of EBM Principles, and thereby advance the application of EBM. The method itself can be built upon in future research endeavors, and at the same time, research on and monitoring of potentially emerging Key Principles such as 'Consider Cumulative Impacts', 'Apply the Precautionary Approach,' and 'Explicitly Acknowledge Trade Offs' will help shape EBM and its ability to accommodate marine governance and management needs of the future.

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