



Trends of the Large Marine Ecosystem assessment and management approach as reflected in the literature

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ARTICLE INFO

Keywords:

Large Marine Ecosystems
Ecosystem-based management
Global environment facility
Transboundary waters

ABSTRACT

The advancement and expansion of a scientific field depends on its ability to organize its findings and establish a basis in the professional literature. In late 2015, a review was undertaken to examine the body of literature regarding the Large Marine Ecosystems (LMEs) of the world. Trends in the literature were studied to explore this approach as a means for implementing ecosystem-based management of coastal and marine resources, with the objective of providing guidance for filling gaps in the scientific literature supporting this concept. Since 1995, there has been an increase in the number of peer-reviewed, scientific journal articles related to the LME approach, termed “LME articles.” Based on this review, we observed that between 1983 and early 2016, 392 LME journal articles were published. In the examined literature, there is a strong focus on fisheries and fisheries-related considerations and concerns, with 59% of the most relevant journal articles focused on fish or fisheries. Future publications should draw on the experience of past and current LME projects to inform and provide tools for future projects to address the socioeconomic aspects of implementing ecosystem-based management. This review also highlights a connection between investments in LME projects by the Global Environment Facility and the amount of corresponding publications regarding the supported LMEs.

1. Introduction

The advancement and expansion of a scientific field depends on its ability to organize its findings and establish a basis in the literature (Braun et al., 2000). First developed in the early 1980s (Sherman and Alexander, 1986), the Large Marine Ecosystem (LME) approach to the assessment and management of coastal ocean goods and services is supported by a substantial body of literature that advanced application of the approach over the past several decades. Numerous publications have described the growing LME community of practice in developing countries, with the support of multilateral development funds, UN agencies, and NGO's. By 2014, 110 developing countries had applied \$3.15 billion in funding catalyzed by the Global Environment Facility (GEF). The GEF is a financial mechanism located within the World Bank to assist developing countries in improving their environmental conditions around the globe. Marine ecosystems provide an estimated \$49.7 trillion in ecosystem services each year (Costanza et al., 2014). Many of these services are concentrated in the coastal areas, which are also the most vulnerable to human activities, such as habitat loss, overexploitation, pollution, and climate change (Millennium Ecosystem

Assessment, 2005; Crain et al., 2009).

Ecosystem-based management of resources requires international, transboundary cooperation to achieve sustainable management. For example, the Humboldt Current is an important upwelling boundary current supporting one of the world's most productive LMEs (Gutiérrez et al., 2016). Cooperation and coordination in environmental and resource management policies and procedures between Chile and Peru, two countries adjacent to the Humboldt Current, is critical to ensuring the health and stability of this important ecosystem. Another example, the Wider Caribbean region, is one of the most geopolitically complex areas of the world (Fanning et al., 2007), where 26 nation states and 19 territories, ranging greatly in size, are highly dependent on the resources of the Caribbean Sea LME (Fanning et al., 2013). There are numerous institutional arrangements in the Caribbean region for governing the ecosystem. Coordination between these different governance entities, supported by the GEF-funded Caribbean Sea and North Brazil Shelf LMEs (the CLME+ Project), encourages movement towards the sustainable development goals set forth in the Caribbean Sea Strategic Action Programme (Debels et al., 2016).

As a framework for supporting transboundary assessment and

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management of coastal and ocean goods and services, the LME concept was developed and introduced at the annual meeting of the American Association for the Advancement of Science in 1984 (Sherman and Alexander, 1986). This approach first established a set of ecological criteria that delineates distinct coastal ocean areas as Large Marine Ecosystems, based on ecological criteria: bathymetry, hydrography, productivity, and trophic interactions (Sherman and Alexander, 1986). The LMEs, which are predominantly coastal, provide 75% of the global marine fisheries yield (Pauly and Lam, 2016). The LME approach includes a methodology for monitoring, assessing, and sustainably managing marine resources within the spatial domain of these regions where they can be subject to management action (Carlisle, 2014). This methodology is based on the temporal and spatial metrics from monitoring and assessing indicators from five LME modules: (i) productivity, (ii) fish & fisheries, (iii) pollution and ecosystem health, (iv) socioeconomics, and (v) governance (Sherman and Duda, 1999). These five modules define suites of indicators that provide structure for the integration of environmental and human dimensions of marine ecosystems, supporting the paradigm shift from single sector management to multidisciplinary and multisectoral ecosystem-based management (EBM) practices (Carlisle, 2014). In a 2005 Scientific Consensus Statement on Marine Ecosystem-based Management, McLeod et al. explain that “Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impact of different sectors.” The five modules are a step towards this cumulative approach and the authors identify LMEs as the broadest spatial classification scale for ecosystem delineation and the implementation of EBM (McLeod et al., 2005).

In 1995, ten years prior to the 2005 Scientific Consensus Statement, the GEF adopted the LME approach as the marine component of its International Waters Focal Area, which addresses transboundary water issues globally. Since that time, the GEF and their United Nations agencies have supported projects in 22 LMEs (see Table 1). These projects use the LME approach to implement ecosystem-based management of coastal and marine resources of one or more countries, using the five modules to provide the metrics to support EBM actions (Sherman, 2014). For each LME project, the GEF has mandated the preparation of a Transboundary Diagnosis Analysis (TDA) to reach consensus on assessment and management priorities, and preparation of a Strategic Action Programme (SAP) to operationalize the objectives for mitigation of stressors for restoring and sustainably managing priority issues identified in the TDA (Duda, 2016).

This objective of restoration and sustainability of marine resources aligns closely with the recently adopted United Nations Sustainable Development Goal (SDG) #14 of the 2030 Agenda for Sustainable Development: Conserve and sustainably use the oceans, seas, and marine resources (General Assembly resolution 70/1, 2015). This SDG embodies the vision advanced by the GEF-funded LME projects for the past two decades. In addition to working towards SDG #14, these projects have also delivered measurable environmental and socioeconomic status improvements directly related to the other SDGs, including ending poverty and hunger, ensuring healthy lives, ensuring sustainable consumption, and taking urgent action to combat climate change and its impacts. For example, the Yellow Sea Large Marine Ecosystem (YSLME) Project promoted and advanced sustainable mariculture that achieved better economic yield for farmers, with less impact on the marine environment than traditional methods (UNDP/GEF, 2012). These project results align with the first (End poverty in all its forms everywhere) and twelfth (Ensure sustainable consumption and production patterns) SDGs. The Chinese government has initiated closed seasons in the YSLME and reduced the number of fishing motor boats by 30% (Tang et al., 2016). Similar actions are underway in the Republic of Korea to recover depleted fish stocks (UNDP/GEF, 2009). These actions are intended to prevent further over exploitation for fisheries, which play critical roles in providing food and income in developing countries, thereby contributing to the first, second (End

hunger, achieve food security and improved nutrition and promote sustainable agriculture), twelfth and fourteenth (Conserve and sustainably use the oceans, seas and marine resources for sustainable development) SDGs. An in-depth analysis of the LME approach as an engine for achieving the SDGs is available (GEF LME:LEARN, 2017).

A substantial body of literature captures the knowledge generated through the development and application of the LME concept and its practice. Until now, this literature had not been reviewed in its entirety and in an organized manner. In late 2015, a library was built for “LME articles,” that is, articles that include, to varying degrees, the LME concept or a specific LME. After gathering and organizing this library, a literature review was undertaken to understand the progress of this concept through trends in the literature and to identify gap areas where future efforts can be focused.

2. Methodology

2.1. Review questions

Several research questions were developed to guide this review and identify trends in the body of LME literature.

- Is the number of LME articles published annually increasing, decreasing, or staying the same?
- Is there a modular focus in the literature?
- Is there a geographic focus in the literature? If so, does it correspond with GEF investments?
- Are there gaps in the topics covered in the literature that should be addressed in future work?

2.2. Literature search strategy

Literature searches for scientific, peer-reviewed journal articles were conducted in late 2015 and early 2016, using the Web of Science database, the Duke University online databases, and the Google Scholar search engine. Keyword search results for each database/search engine were first screened based on inclusion and exclusion criteria. The full text article was retrieved for each result entry that met these criteria. The *Find* tool was used to check the entire document for keywords. Documents with at least one of the keywords were imported to EndNote, which was used to organize and compile a literature library. These articles will henceforth be referred to as “LME articles.”

In addition to peer-reviewed journal articles, eighteen books have been published on the LME approach since 1986 – the LME Volumes. Studies reported in these seminal volumes have provided a growing scientific foundation for practicing the LME Approach to the assessment and management of coastal and ocean goods and services. Each volume consists of a number of chapters ranging from nine to forty-two and has a general focus, typically a geographic range or a topic such as climate change or human dimensions of LMEs. Although they are peer-reviewed, these volumes were not included in the count of LME articles.

2.2.1. Keyword search criteria

The keywords used to search for LME articles were (Large marine ecosystem), (Large marine ecosystems), (LME), and (LMEs).

2.2.2. Inclusion and exclusion criteria

Inclusion and exclusion criteria helped identify the articles relevant to this study.

Inclusion criteria included: i) keywords in the abstract, key words, or the full text of the document at least once, and ii) published between 1983 and present day.

Exclusion criteria included: i) book chapters, ii) dissertations/theses not published in an academic journal, iii) conference papers not published in an academic journal, and iv) not in English. The exclusion of literature in non-English languages is not to imply that these sources are

Table 1
List of LME projects and countries funded by the GEF (reproduced from [Sherman, 2014](#)).

Large Marine Ecosystem Projects			
LME	Country	Project Title	Catalyzed Funding in US\$ millions
Agulhas Current; Somali Coastal Current	Comoros; Kenya; Madagascar; Mauritius; Mozambique; Seychelles; South Africa; Tanzania United Republic of	Programme for the Agulhas and Somali Current Large Marine Ecosystems: Agulhas and Somali Current Large Marine Ecosystems Project	30.436
Agulhas Current; Benguela Current; Canary Current; Guinea Current; Somali Coastal Current	Targets: Canary Current (West Africa), Guinea Current (Gulf of Guinea), Benguela Current (Namibia, Angola, South Africa), Agulhas Current (South Africa, Mozambique, Comoro Islands, Seychelles, Madagascar, Mauritius), and Somali Current (Tanzania, Kenya, Somali)	Strategic Partnership for a Sustainable Fisheries Investment Fund in the Large Marine Ecosystems of Sub-Saharan Africa (Tranche 1, Installment 1)	80.073
Agulhas Current; Benguela Current; Canary Current; Guinea Current; Somali Coastal Current	Targets: Canary Current (West Africa), Guinea Current (Gulf of Guinea), Benguela Current (Namibia, Angola, South Africa), Agulhas Current (South Africa, Mozambique, Comoro Islands, Seychelles, Madagascar, Mauritius), and Somali Current (Tanzania, Kenya, Somali)	Strategic Partnership for a Sustainable Fisheries Investment Fund in the Large Marine Ecosystems of Sub-Saharan Africa (Tranche 1, Installment 2)	127.240
Agulhas Current; Somali Coastal Current	Comoros; Kenya; Mozambique, South Africa, Tanzania United Republic of; Mauritius; Seychelles	Southwest Indian Ocean Fisheries Project	34.950
Agulhas Current, Indian Ocean, Somali Coastal Current	Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Tanzania, South Africa	Addressing Land-based Activities in the Western Indian Ocean	11.413
Baltic Sea	Estonia; Latvia; Lithuania; Poland; Russian Federation	Baltic Sea Regional Project, Phase 1	12.450
Bay of Bengal	Bangladesh; India; Indonesia; Malaysia; Maldives; Myanmar; Sri Lanka; Thailand	Bay of Bengal Large Marine Ecosystem	28.468
Benguela Current	Angola; Namibia; South Africa	Implementation of the Strategic Action Programme (SAP) Toward Achievement of the Integrated Management of the Benguela Current Large Marine Ecosystem	38.564
Benguela Current	Angola; Namibia; South Africa	Implementation of the Benguela Current LME Action Program for Restoring Depleted Fisheries and Reducing Coastal Resources Degradation	67.167
Benguela Current	Angola; Namibia; South Africa	Distance Learning and Information Sharing Tool for the Benguela Coastal Areas	1.546
Black Sea	Bosnia and Herzegovina; Bulgaria; Croatia; Czech Republic; Hungary; Moldova Republic of; Romania; Serbia and Montenegro; Slovakia; Slovenia; Ukraine	Strengthening the Implementation Capacities for the Nutrient Reduction and Transboundary Cooperation in the Danube River Basin-Phase 1 Project	11.950
Black Sea	Bulgaria, Croatia, Czech Rep., Hungary, Moldova, Romania, Slovakia Rep., Slovenia, Ukraine, Yugoslavia & Serbia	Strengthening the Implementation Capacities for Nutrient Reduction and Transboundary Cooperation in the Danube River Basin	24.878
Black Sea	Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Georgia, Hungary, Moldova Republic of, Romania, Russian Federation, Serbia and Montenegro, Slovakia, Slovenia, Turkey, Ukraine	Danube/Black Sea Basin Strategic Partnership on Nutrient Reduction: Tranche 1	29.55
Black Sea	Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Georgia, Hungary, Moldova Republic of, Romania, Russian Federation, Serbia and Montenegro, Slovakia, Slovenia, Turkey, Ukraine	Danube/Black Sea Basin Strategic Partnership on Nutrient Reduction Fund: Tranche 2	76.550
Black Sea	Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Georgia, Hungary, Moldova Republic of, Romania, Russian Federation, Serbia and Montenegro, Slovakia, Slovenia, Turkey, Ukraine	Strategic Partnership for Nutrient Reduction in the Danube River and Black Sea – World Bank – GEF Nutrient Reduction Investment Fund: Tranche 3	225.100
Black Sea	Bulgaria; Georgia; Romania; Russian Federation; Turkey; Ukraine	Control of Eutrophication, Hazardous Substances and Related Measures for Rehabilitating the Black Sea Ecosystem: Phase 1	7.945
Black Sea	Bulgaria; Georgia; Romania; Russian Federation; Turkey; Ukraine	Control of Eutrophication, Hazardous Substances and Related Measures for Rehabilitating the Black Sea Ecosystem, Tranche 2	11.332
Canary Current	Cape Verde; Gambia; Guinea; Guinea-Bissau; Mauritania; Morocco; Senegal	Protection of the Canary Current Large Marine Ecosystem	26.506
Caribbean Sea	Cuba, Jamaica	Demonstrations of Innovative Approaches to the Rehabilitation of Heavily Contaminated Basin the Wider Caribbean	32.770
Caribbean Sea	Cuba; Barbados; Jamaica; Mexico; Venezuela; Antigua and Barbuda; Bahamas; Belize; Brazil; Colombia; Costa Rica; Dominica; Dominican Republic; Grenada; Guatemala; Guyana; Haiti; Honduras; Nicaragua; Panama; Saint Kitts and Nevis; Saint Lucia; Saint Vincent and the Grenadines; Suriname; Trinidad and Tobago	Sustainable Management of the Shared Marine Resources of the Caribbean Large Marine Ecosystem and Adjacent Regions	55.380
Caribbean Sea	Antigua and Barbuda, Bahamas, Barbados, Cuba, Dominica, Dominican Republic, Jamaica, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago	Integrating Watershed and Coastal Area Management in the Small Island Developing States of the Caribbean	111.652
Caribbean Sea	Colombia; Costa Rica; Nicaragua	Reducing Pesticide Runoff to the Caribbean Sea	10.042

(continued on next page)

Table 1 (continued)

Large Marine Ecosystem Projects			
LME	Country	Project Title	Catalyzed Funding in US\$ millions
Caribbean Sea	Antigua and Barbuda; Barbados; Costa Rica; Guatemala; Guyana; Honduras; Saint Lucia; Suriname; Panama; Jamaica; Belize; Trinidad and Tobago	Testing a Prototype Caribbean Regional Fund for Wastewater Management	271.500
East Asia	China, Thailand, Viet Nam	Livestock waste management in East Asia	24.006
East China Sea; South China Sea; Gulf of Thailand; Yellow Sea; Sulu-Celebes Sea; Indonesian Sea	Cambodia; China; Korea Democratic People's Republic of; Korea Republic of; Indonesia; Japan, Lao People's Democratic Republic; Philippines; Singapore; Timor-Leste; Viet Nam	Implementation of Sustainable Development Strategy for the Seas of East Asia	44.250
East China Sea; South China Sea; Gulf of Thailand; Yellow Sea; Sulu-Celebes Sea; Indonesian Sea	Cambodia, China, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Thailand, Viet Nam	World Bank/GEF Partnership Investment Fund for Pollution Reduction in the Large Marine Ecosystems of East Asia (Tranche 1 of 3 tranches)	464.368
East China Sea; South China Sea; Gulf of Thailand; Yellow Sea; Sulu-Celebes Sea; Indonesian Sea	Cambodia, China, Indonesia, Lao People's Democratic Republic, Malaysia, Philippines, Thailand, Viet Nam	World Bank/GEF Partnership Investment Fund for Pollution Reduction in the Large Marine Ecosystems of East Asia (Tranche 1, Installment 2)	85.870
Guinea Current	Angola; Benin; Cameroon; Congo; Cote d'Ivoire; Equatorial Guinea; Ghana; Guinea; Guinea-Bissau; Liberia; Nigeria; Sierra Leone; Togo; Gabon; Congo the Democratic Republic of; Sao Tome and Principe	Combating Living Resource Depletion and Coastal Area Degradation in the Guinea Current LME through Ecosystem-based Regional Actions	54.683
Gulf of Mexico	Mexico, USA	Integrated Assessment and Management of the Gulf of Mexico Large Marine Ecosystem	101.277
Gulf of Thailand; South China Sea	China	Biodiversity Management in the Coastal Area of China's South Sea – marine biodiversity, ecosystem management and marine biodiversity monitoring	46.605
Gulf of Thailand; South China Sea	Indonesia	Demonstration of Community-based Management of Seagrass Habitats in Trikora Beach East Bintan, Riau Archipelago Province, Indonesia	0.790
Humboldt Current	Chile; Peru	Towards Ecosystem Management of the Humboldt Current Large Marine Ecosystem	32.115
Mediterranean Sea	Albania; Algeria; Bosnia and Herzegovina; Croatia; Egypt; Lebanon; Libyan Arab Jamahiriya; Morocco; Montenegro; Syrian Arab Republic; Tunisia; Turkey	Strategic Partnership for the Mediterranean Large Marine Ecosystem – Regional Component: implementation of agreed actions for the protection of the environmental resources of the Mediterranean Sea and its coastal areas	49.439
Mediterranean Sea	Algeria; Albania; Bosnia and Herzegovina; Bulgaria; Croatia; Egypt; Macedonia the former Yugoslavian Republic of; Morocco; Serbia and Montenegro; Syrian Arab Republic; Tunisia; Turkey	World Bank – GEF Investment Fund for the Mediterranean Sea Large Marine Ecosystem Partnership, Tranche 1, 1st Allocation	96.055
Mediterranean Sea	Albania; Algeria; Bosnia and Herzegovina; Bulgaria; Croatia; Egypt; Macedonia the former Yugoslavian Republic of; Lebanon; Libyan Arab Jamahiriya; Monaco; Morocco; Serbia and Montenegro; Syrian Arab Republic; Tunisia; Turkey	World Bank – GEF Investment Fund for the Mediterranean Sea Large Marine Ecosystem Partnership, Tranche 1, 2nd Installment	60.000
Mediterranean Sea	Albania, Algeria, Bosnia and Herzegovina, Egypt, Lebanon, Libyan Arab Jamahiriya, Morocco, Syrian Arab Republic, Tunisia	MED Integration of Climatic Variability and Change into National Strategies to Implement the ICZM Protocol in the Mediterranean	9.298
Mediterranean Sea	Tunisia	MED Greater Tunis Treated Wastewater Discharge in the Mediterranean Sea	555.000
Pacific Central American Coastal	El Salvador, Honduras, Nicaragua	Integrated Ecosystem Management Pilot for the Gulf of Fonseca	26.326
Patagonian Shelf	Argentina, Uruguay	Reducing and Preventing Land-based Pollution in the Rio de la Plata/Maritime Front Through Implementation of FrePlata Strategic Action Programme	170.870
Patagonian Shelf	Argentina; Uruguay	Environmental protection of the Rio de la Plata and its Maritime Front: Pollution Prevention and Control and Habitat Restoration	10.480
Red Sea, Arabian Sea	Djibouti; Egypt; Jordan; Saudi Arabia; Sudan; Yemen	Red Sea and Gulf of Aden Strategic Ecosystem Management	38.00
Red Sea, Arabian Sea	Djibouti; Egypt; Jordan; Saudi Arabia; Sudan; Yemen	Implementation of the Strategic Action Programme for the Red Sea and Gulf of Aden	44.650
Red Sea, Arabian Sea	Yemen	Protection for the Marine Ecosystem of the Red Sea	2.800
Sulu-Celebes Sea	Indonesia; Malaysia; Philippines	CTI Sulu-Celebes Sea Sustainable Fisheries Management Project	6.310
Yellow Sea	China; Korea Republic of	Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem	24.696
Total number of countries with GEF-funded projects: 110		Total Funds	3155.195

not relevant, but was based on the language skills of the investigators. Further along in the analysis, it was determined that some of the articles that passed the inclusion and exclusion criteria referred to ecosystems that are large, but not actually one of the 66 “LMEs.” These articles were excluded when it was determined that they were not discussing the formal LME framework and concept.

2.3. Ranking and labeling

After the literature was selected for inclusion in the library, it was placed in one of five groups based on relevancy to LMEs (see Table 2). For example, articles in Group One mention an LME or the LME approach once or twice, while articles in Group Five are about the LME

Table 2
Descriptions of the LME literature groupings based on relevancy.

LME Literature Grouping		
Group	Description	Number of Articles
1	These journal articles mention the LME approach or a specific LME. Included in this group are papers that simply reference key LME works.	50
2	These journal articles include a discussion, sometimes abbreviated, of the LME approach or a specific LME, between a few sentences and a couple of paragraphs; however, LMEs and the LME approach are not a focus of the work.	38
3	These papers are works that have a focus on an LME or the LME approach, but are not LME studies.	83
4	This group includes LME studies and studies that use LMEs as the study area.	122
5	These are the key LME publications, works that discuss the LME approach and further develop the application of the approach.	99
LME Volumes	These eighteen seminal volumes developed the LME concept.	N/A

approach itself. The groups are described in detail in Table 2. Articles in Groups Three, Four, and Five were also labeled by module (i.e. Productivity, Fish and Fisheries, Pollution and Ecosystem Health, Socioeconomics, or Governance) if they specifically focus on one or more of these areas. Articles were also labeled based on geographic focus on one or more specific LMEs.

2.3.1. Volumes labeling

The chapters of the LME Volumes were not ranked, but were labeled with the same criteria used for labelling the LME articles. Chapters were labeled by module (i.e. Productivity, Fish and Fisheries, Pollution and Ecosystem Health, Socioeconomics, or Governance) if they specifically focus on one or more of these areas. Seven of the volumes have a specific geographic focus: The Northeast U.S. Shelf Ecosystem, the Indian Ocean, The Gulf of Mexico, the Pacific Rim, the Gulf of Guinea, the North Atlantic, and the Benguela Current.

2.4. Analysis

The LME literature was analyzed to answer specific review questions. To determine if the number of LME articles published annually is increasing, decreasing, or staying the same, a publication frequency chart was constructed. Starting in 1995, the year the GEF adopted the LME approach as the marine component of the International Waters Focal Area, the LME articles were graphed by year. The graph also indicates for which years the LME volumes were published. Next, both the papers and volume chapters with a modular focus were tallied to determine if the literature tends to focus on a specific module. Pie charts were constructed to examine potential trends.

Lastly, trends in the geographical focus of the LME literature were explored. It was hypothesized that, given the substantial investments of the GEF in specific LMEs for the purpose of improved transboundary marine resource assessment and management, these regions would publish more scientific articles as a result of those investments. The papers with a focus on one or more specific LMEs were tallied and a list of the “top published” LMEs was compiled. A graduated symbols map was created to examine potential trends. The locations of the geographically-focused LME volumes are also indicated. Using Table 1, a second map was created to show the distribution of the funding catalyzed by the GEF for LME projects. Funding for projects with multiple LMEs was counted for each country involved in the project.

3. Results

Since 1995, when the GEF formally adopted the LME approach as the marine component of its International Waters focal area, 392 scientific journal articles have been published regarding LMEs. These papers vary in their relevance to the LME approach. Some articles mention the topic once, while others are focused solely on the framework or a specific region. The number of published LME journal articles has greatly increased over the years (Fig. 1). In 2016, a thematic issue of *Environmental Development* entitled *Ecosystem Based Management of*

Large Marine Ecosystems was published. This work was coordinated through the National Oceanic and Atmospheric Administration (NOAA) LME Program.

A total of 141 of the 304 scientific journal articles across groups Three, Four, and Five were determined to have a specific modular focus. Fig. 2, Panel 1 shows a clear dominance in the literature by the Fish & Fisheries module, with over half (59%) of the articles addressing this topic. The Governance and Productivity modules are the next two largest categories; representing between 14% and 16% of the total, respectively. The Pollution and Ecosystem Health module was 8% of this literature. The Socioeconomics module was relatively deficient in the number of articles specifically addressing this topic. The modular focus across the volumes differed. Fig. 2, Panel 2 also shows a clear dominance by the Fish & Fisheries module (38%). The Governance and Pollution & Ecosystem Health modules made up 25% and 20% of the module-focused chapters, respectively. The Socioeconomics module made up 8% and the Productivity module made up 8%.

Fig. 3 explores the geographic distribution of the LME journal articles. It shows geographically where LME papers are focused. The LMEs with the largest number of publications are listed in Table 3. The Benguela Current, Gulf of Mexico, Guinea Current, Agulhas Current, Somali Coastal Current, and Canary Current LMEs are all the location of GEF-funded projects, using the LME approach. In the United States, through the NOAA, regional management occurs in the spatial boundaries of the California Current and Northeast U.S. Continental Shelf LMEs, as well as other LMEs. Some of the LMEs with one or no articles include the Northern Australian Shelf LME, the Norwegian Sea LME, the Oyashio Current LME, and the Iberian Coastal LME. These are all LMEs where the GEF has not funded LME projects, and thus, the LME approach has not been applied.

Fig. 4 explores the geographic distribution of the GEF-catalyzed funding, showing geographically where LME project funding is focused (based on Table 1). The LMEs with the most funding are the Mediterranean Sea, the South China Sea, the Gulf of Thailand, the Yellow Sea, the Sulu-Celebes Sea, the East China Sea, the Indonesian Sea, the Caribbean Sea, the Black Sea, the Benguela Current, and the Agulhas and Somali Coastal Currents.

4. Discussion

The trend of increasing publications on the subject of LMEs is indicative of the use of the LMEs as ecologically defined spatial domains for the assessment and management of coastal ocean goods and services. The LME approach is being further developed with the inclusion of increasing numbers of marine protected areas and marine spatial planning projects. As the framework is employed and further developed in new regions and in conjunction with other management approaches (e.g. marine protected areas and marine spatial planning), the overall body of literature explored in this study grows. The LME Volumes appear to have played a key role in bolstering the concept and facilitating further development in scientific journals. Notable steps forward include the Sea Around Us research initiative, which uses LMEs spatial

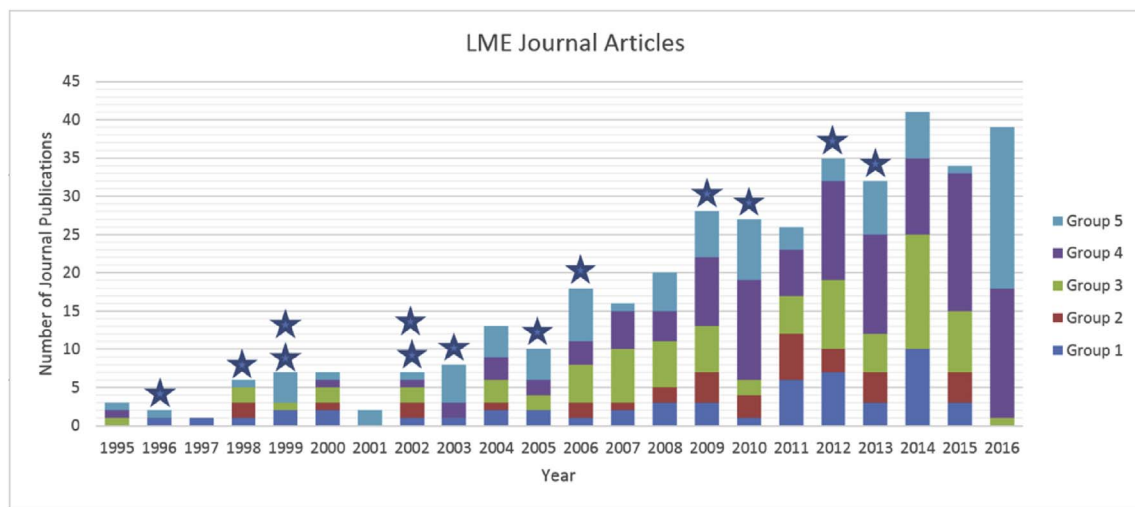


Fig. 1. Large Marine Ecosystem papers published by year. Colors indicate the grouping composition of each year's publication. Stars above the bar indicate that an LME Volume was published this year. Two stars indicate that two LME volumes were published. An additional five volumes were published prior to 1995.

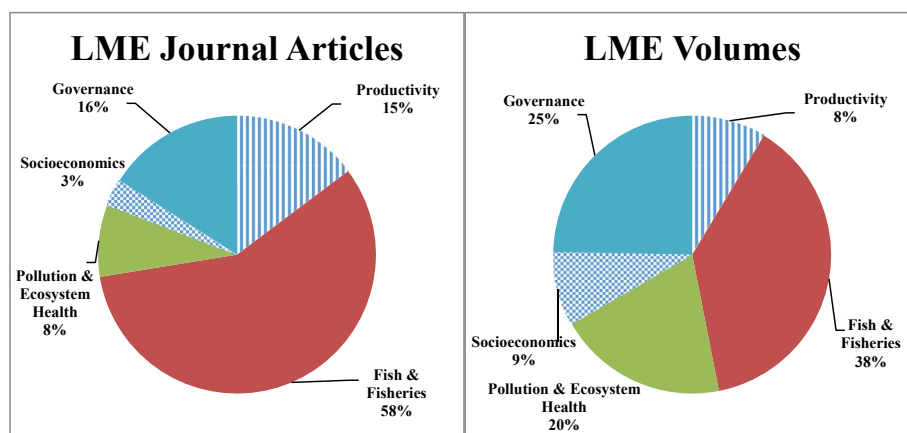


Fig. 2. Percentage of LME Journal Articles and the LME Volumes with modular focus. In the LME Journal Articles and in the LME Volumes, the Fish & Fisheries module was the focus of 58% and 38% of the literature with a modular focus, respectively. Governance was 16% and 25%. Productivity was 15% and 8%. Pollution and Ecosystem Health was 8% and 20%. Socioeconomics was 3% and 9%.

boundaries as global assessment units for analyzing global fisheries trends. Some of the more highly cited LME literature includes [Worm et al., 2009](#), which analyzes the results of increased efforts to rebuild marine fisheries and describes a decline in the average exploitation rate in half of ten well-studied LMEs. This article itself has been cited in over 1500 scientific articles.

The present study found a clear focus on the Fish & Fisheries module in both the journal literature and the LME Volumes. This fisheries focus has also been identified in some of the GEF-funded projects. For example, the GEF recently funded the Coastal Fisheries Initiative for US \$34.1 million of GEF resources ([GEF, 2016](#)). This Initiative is designed to complement the LME approach and, while these efforts are important, future work should focus on ecosystem-based management that incorporates other important aspects of the ecosystem beyond fisheries. The low number of articles addressing the Socioeconomics module of the LME approach indicates the need to focus future efforts on this area. Although it does not appear to be reflected in the literature, efforts are currently being made to address this module by the LME Projects. For example, the TDA for the Canary Current Large Marine Ecosystem (CCLME) Project explored the socioeconomic importance of the region ([CCLME Project, 2016a,b](#)). The data informing the TDA also evaluated the goods and services of this ecosystem. For example, the value of mangroves, seagrass-beds and dunes were considered. The Strategic Action Programme (SAP), a plan of action based on the findings of the TDA, describes activities to further explore ecosystem valuation of the CCLME ([CCLME Project, 2016a,b](#)). Another example is in the Bay of

Bengal Large Marine Ecosystem (BoBLME) Project, where social and economic considerations are one of the four main themes around which the SAP is built ([BoBLME, 2015](#)).

The geographic distribution of the LME literature ([Fig. 3](#)) supports the hypothesis that LMEs with GEF-funded projects have more published LME-related scientific literature. This hypothesis was further supported by [Fig. 4](#), showing the distribution of GEF-catalyzed LME project funding. The Benguela Current LME has received substantial GEF investments, which resulted in the signing of the Benguela Current Convention in 2013 ([Hamukuaya et al., 2016](#)). The Benguela Current Commission (BCC) is active in the region with a Science Program charged with providing the BCC and Contracting Parties with the best available scientific advice for regional management of the BCLME from an EBM management perspective, as well as an Annual Science Forum ([Vaz Velho, 2014](#)). The Gulf of Mexico LME, the Guinea Current LME, the Agulhas and Somali Currents LMEs, and the Canary Current LME also are the locations of GEF-funded projects. There are two notable departures between the two figures. The first regards the relatively large amount of catalyzed funding in the eastern Asian LMEs (e.g. South China Sea LME, Gulf of Thailand LME, etc.) This may be due to the language limitation of this study. Only articles in English were included in this review. Articles resulting from the LME projects in these LMEs may have been published in languages other than English. The second difference is the relatively high number of publications on North American LMEs (e.g. the California Current LME, the Northeast Continental Shelf LME, etc.)

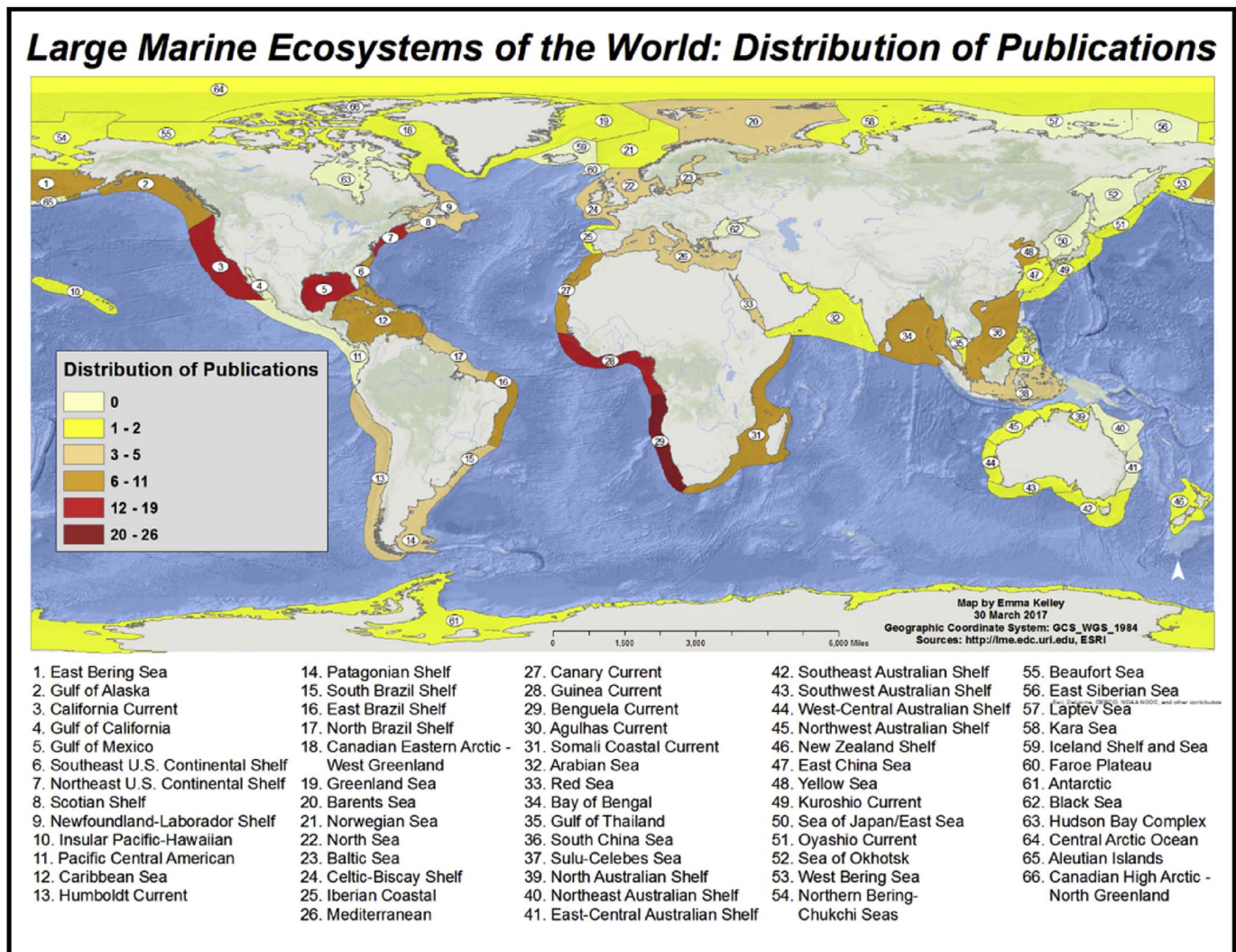


Fig. 3. The geographic distribution of the LME scientific journal articles.

Table 3

The LMEs with the largest number of publications. The Agulhas Current and Somali Coastal Current LMEs, although separate, are treated as one area.

Geographic Distribution of LME Publications	
Large Marine Ecosystem	Number of Academic Journal Publications
Benguela Current	26
California Current	19
Gulf of Mexico	16
Northeast U.S. Continental Shelf	15
Guinea Current	13
Agulhas and Somali Currents (2)	11
Canary Current	10

As previously stated, out of the top eight highly-published LMEs, only two have not been the recipient of GEF funds: the Northeast U.S. Continental Shelf LME and the California Current LME. These regions are the location of substantial research activity by NOAA, as well as numerous academic institutions and other organizations that have contributed to our understanding of these areas. Also, Dr. Sherman and Dr. Alexander first conceived their LME approach based on experience in the Northeast U.S. Continental Shelf LME and later, the California Current LME, producing publications on these regions, and also developing and promoting the Marine Resources Monitoring Assessment and Prediction (MARMAP) program as a precursor to the LME concept

(Sherman, 2015).

The connection between GEF investments in a region and a higher number of scientific journal publications referencing LMEs may be explained by activities these investments fund. In the first phase of an LME project, participating countries complete a TDA to identify their priority transboundary environmental concerns, such as poor water quality, overexploited fisheries, degraded habitats, etc. This process sometimes involves baseline studies to provide an understanding of the current status of an LME. For example, fish surveys were conducted in the Benguela Current LME (BCLME) through the Benguela Environment Fisheries Interaction and Training Programme (BENEFIT), a precursor to the BCLME Program. These surveys were in collaboration with the Norwegian Agency for Development Cooperation's Nansen Program (Bianchi et al., 2016) and the German GIZ program (Bers et al., 2016). Scientific publications are frequently the result of not just the studies supporting the TDA, but activities undertaken later by projects to continue the movement towards EBM, as was the case with the BCLME Project and the BCC (e.g. Sowman and Cardoso, 2010; Harris et al., 2013). Further, the two-decades of inter-governmental collaboration towards the implementation of EBM in the BCLME was the subject of an article in the 2016 thematic issue of Elsevier Science's journal *Environmental Development* on the ecosystem-based management of Large Marine Ecosystems. The final article in the issue was written by twelve ministers from the three BCLME countries: Angola, Namibia, and South Africa. The ministers highlight the achievements of this collaboration

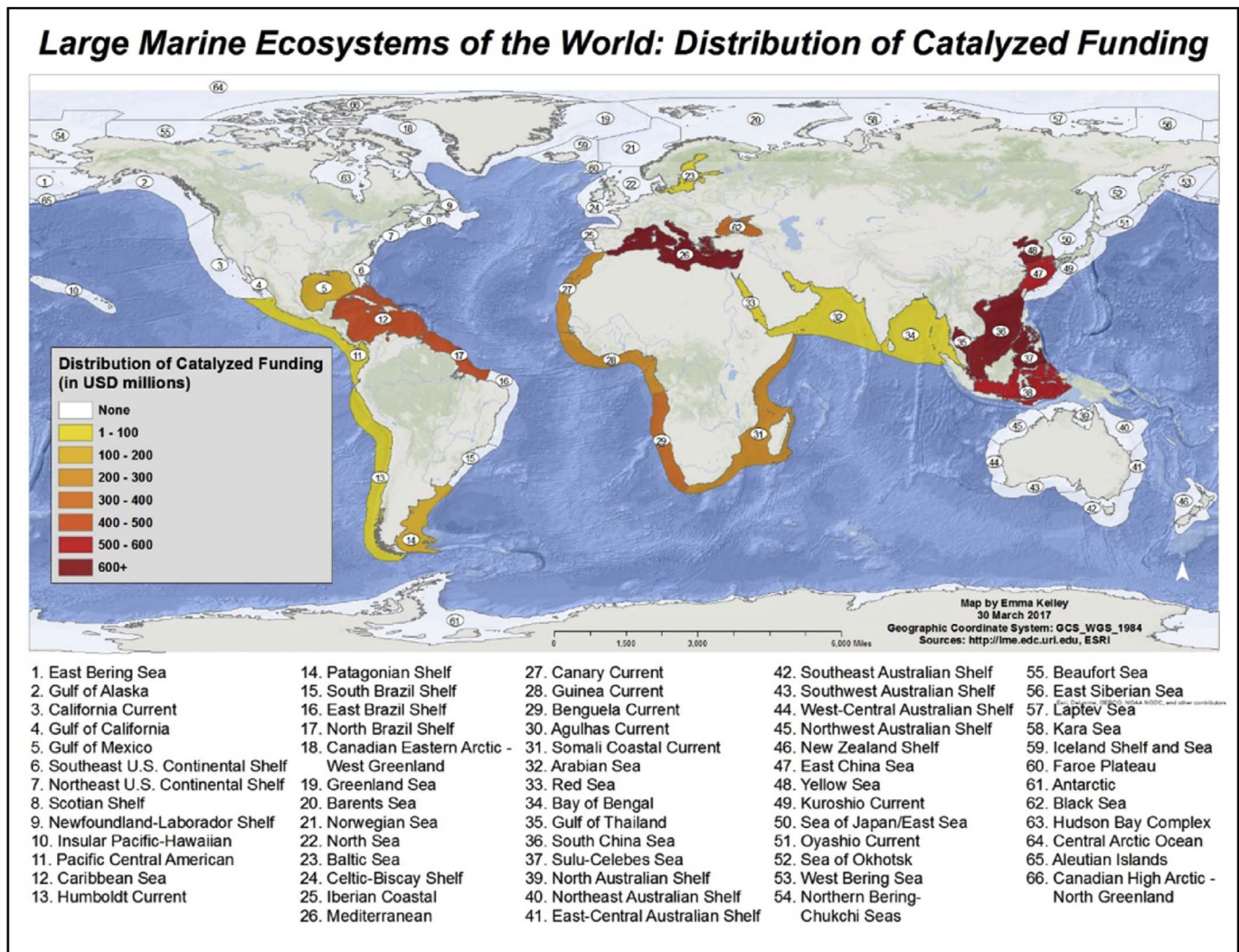


Fig. 4. The geographic distribution of the funding catalyzed by the GEF for LME projects.

on ocean management and reinforce the importance of an ecosystem-based, multi-sectoral approach to marine resource management in the BCLME (de Barros Neto et al., 2016).

Although only articles from scientific journals and the peer-reviewed LME volumes were included in this study, reports from the organizations working on the GEF-funded projects are also an indicator of the status of the concept. Specifically, reports describing the results and accomplishments of these programs provide context for some of the scientific literature. In 2012, UNDP published the report “International Waters: Delivering Results.” The first chapter describes the UNDP-GEF joint effort to support over 100 countries engaged in GEF-funded LME projects and the key results of these projects. In 2015, the GEF released a publication entitled “From Coast to Coast: Celebrating 20 Years of Transboundary Management of our Shared Oceans” which describes some of the key accomplishments of the International Waters focal area. In the lead chapter on LMEs, the authors describe that “... the LME approach is the cornerstone of the GEF strategy for ocean and coastal conservation and the GEF is the leading global funding source for transboundary water systems” These two reports were distributed at the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change convened in Paris in December 2015.

5. Conclusions

The findings of this study point to the growth and development of the LME approach from its origins at the 1984 the annual meeting of the American Association for the Advancement of Science, to the presentation of the results of LME projects at COP21. The observation that GEF investments in LMEs are related with more publications regarding these LMEs is evidence of the impact of these activities.

As the GEF prepares for its seventh replenishment, these findings suggest that there is a growing literature trend describing results of LME studies that are consistent with advancing towards the United Nations Sustainable Development Goal for conserving and sustainably using the oceans, seas, and marine resources of the globe (General Assembly resolution 70/1, 2015).

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