

Review

# Combining Marine Ecology and Economy to Roadmap the Integrated Coastal Management: A Systematic Literature Review

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Received: 24 June 2019; Accepted: 9 August 2019; Published: 14 August 2019



**Abstract:** Integrated coastal management (ICM) relies on the inclusion of economic issues within marine ecology. To assess the progress of this integration, we applied topic modelling and network analysis to explore the pertinent literature (583 Isi-WoS, and 5459 Scopus papers). We classified the topics of interest (i.e., concepts, approaches, and sectors) that combined ecological and economic issues within marine science, we aggregated these topics in fields pertinent to ICM, and tracked the knowledge-exchange between these fields by using an information-flow network. Main findings were: (i) the high trans-disciplinary fashion of studies about marine protection and of those about commercial fisheries, (ii) the weak interaction between studies focusing on potential biohazards and those about environmental management, (iii) the isolation, in the overall information-flow, of studies about ecotourism and aquaculture. We included in a roadmap all the integration routes we detected within ICM, based on the combination of ecological and economic issues. We conclude that, to improve integration, ICM should: (i) Exploit marine protection as a bridge between ecological and economic concepts and approaches, and between maritime economy sectors, (ii) employ systems ecology to pursue trans-disciplinary investigations, (iii) complement systems ecology with citizen science by means of inclusive economic initiatives, such as ecotourism.

**Keywords:** coastal resilience; ecological economics; integrated coastal management; marine ecology; marine/maritime economy; socio-ecological systems; network science; topic modelling

## 1. Introduction

Coastal areas sustain human populations at any spatial scale [1]. These areas are socio-ecological systems, where natural processes, occurring in the biophysical environment, and human activities, mostly concentrated in the urbanized regions, are tightly interconnected [2–4]. In the present era of impressive population growth along the coasts, sustainability science envisions “blue cities” alongside waterfronts (see, e.g., [5]), in which human activities should be able to manage the coasts in a way that these latter maintain their resilience, i.e., they absorb the unavoidable anthropogenic impacts, keep functioning, and provide goods and services to humans [6–8].

Coastal management is asked to govern the economic exploitation of the land-sea interface based on: (i) the assessment of the present natural features, (ii) the prediction of the future environmental degradations, and (iii) the evaluation of the economic potential if the environment is managed to maximize harvest in a sustainable way (e.g., see the Evolutionary Governance Theory, [9]). To this latter end, in line with several international political documents (e.g., see the Millennium Ecosystem Assessment [10], and the Economics of Ecosystem and Biodiversity [11]), the integrated coastal

management (ICM) should reconcile some seemingly antithetic disciplines, such as marine ecology and maritime/marine economy [6–8,12]. In fact, ecology focuses on the interactions between the physical factors and the biological realms, while economy studies the monetary exchanges among single persons, corporations, and nations. The need for combining these different ambits led to the introduction of the so-called ecological economics, a discipline that is becoming a key pillar of coastal management [13,14].

This systematic literature-review is conducted from the perspective of marine ecologists, and it aims at assessing how and to which extent marine ecology includes economic issues. This assessment can provide important hints about the level of conceptual integration of marine ecology with marine/maritime economy, providing positive feedback to roadmap the management of coastal, and populated areas. Under a semantic point of view, the integration of different disciplines is more likely accomplished if their combination within a unifying framework gives rise to a coherent language [15]: *c.*, the same words are used to define common topics of interest, and these topics aggregate in disciplinary fields which, though reciprocally distinct (e.g., they could include different arrays of topics), overlap thanks to the topics shared.

In particular, the questions addressed herein are: (i) How many scientific publications about marine systems combine ecological and economic issues? (ii) Which words can provide possible conceptual links between ecology and economy? (iii) Which topics, being either sustainability concepts (e.g., ecosystem services, etc.), management approaches (e.g., marine protected areas, etc.) or marine/maritime economy sectors (e.g., coastal fishery), result from the combination of these words? (iv) Which disciplinary fields emerge from the aggregation of topics, based on the shared words? (v) What is the level of integration between fields, based on shared topics?

To pursue the above-mentioned aims, we: (i) revise a copious literature pertaining to marine ecological studies that include economic issues, and explore it with topic modelling [16], (ii) identify the most frequently shared terms (made of one or more words) between papers, (iii–iv) categorize topics and aggregate them within the main disciplinary fields contributing to the integrated coastal management, such as environmental conservation, evaluation of anthropogenic impacts and management of habitats and natural resources [6–8], and (v) by means of network analysis, we detect the main connection pathways among fields, as promoted by the combination of marine ecology and economy. Building on our results, we roadmap the development of more integrative practices within the coastal management.

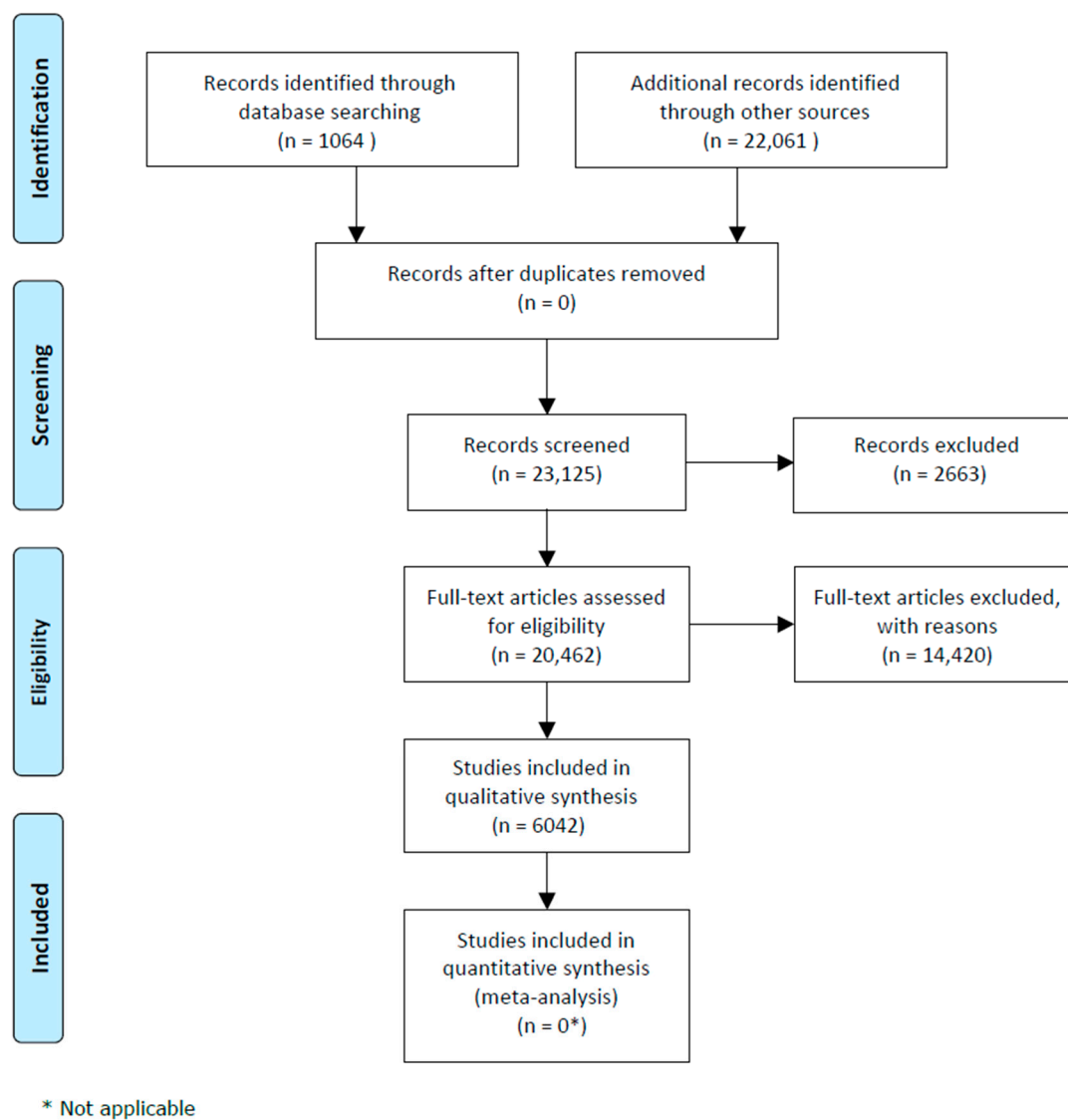
## 2. Material and Methods

Our analytical approach aimed to gather a body of publications starting from the titles and abstracts of scientific articles recorded in public and referenced databases, such as ISI and Scopus. By limiting our study to titles and abstracts, we excluded biases in the construction of information-flow networks introduced by the sharing of words which are not strictly related to scientific contexts. Even though information flows can be also established via cross-referencing emerging in the articles' bodies, our primary focus was on the integration, instead of the simple information sharing. We believe that the integration of different disciplines, if present, should emerge at the highest hierarchical levels of the paper's structure. If it is not present in the paper's title, it should appear in the paper's abstract, at least.

As for the semantics that we adopted, in a preliminary search, we assessed that the word ecology is largely associated with the adjective marine, while the word economy is associated with both marine and maritime, this latter adjective being mainly referred to shipments and transportations. In fact, in the scientific literature referring to marine policy—*i.e.*, the background for integrated coastal management—the wording marine economy appeared twice as frequent as the maritime economy (see, e.g., [17]). For the latter reason, we decided to harmonize our semantics and run our search by adopting the adjective marine in association with both ecology and economy.

We started our analytical examination of the literature pertaining to the integration between ecology and economy in the sea by examining 583 papers. Then, we filtered these papers (by eliminating

non-pertinent publications) and used the remnant ones ( $n = 368$ ) as a training set for a probabilistic topic model. The model produced fifteen topics that were clustered into the ICM fields management, conservation, and impacts [6–8]. We explored similarities among papers, and then applied the model to a more extensive dataset (5459 papers) to examine topic repartition in time. We performed all the analyses within the R software environment for statistical computing [18]. This systematic review has been carried out according to the PRISMA guidelines [19] (Figure 1).



**Figure 1.** PRISMA flowchart describing the literature sorting within this review.

### 2.1. Training Data Acquisition

We acquired the first and smaller dataset searching on all databases for the combination of words “marine AND ecology AND economy” in the period 1991–2018 through the Web of Science (WoS, <https://clarivate.com/products/web-of-science/>) Basic Search. We downloaded search results in csv, and deleted entries without DOI. We scanned the remaining entries for inconsistencies (i.e., abstract content not conceptually related to search terms), and we imported the resulting dataset in R, where it was reshaped using tools from the tidyverse package collection (<https://www.tidyverse.org/>). We stripped the validated dataset of uninformative columns, maintaining only WoS ID, title, and abstract, and then joined the latter two in a single column.

## 2.2. Topic Model Construction

For the model building steps, we choose the textmineR package (<https://CRAN.R-project.org/package=textmineR>). We used the reshaped and tidied data frame as the training input for the creation of a Document-term matrix (DTM) with both single words, like coral and reef, and bigrams (i.e., sequences of two words), like coral reef. To screen for unwanted words, we calculated term frequency for the entire DTM. The number of topics was found measuring probabilistic coherence, (i.e., how associated words are in a topic, controlling for statistical independence) with the CalcProbCoherence() function for ten repetitions of the [1:100] topic range and four repetitions of the [1:256] topic range, choosing the number of topics that maximize overall coherence. We then repeatedly ( $n = 10$ ) fitted the topic model (FitLdaModel() function) to the training data, and we considered the best repetition (i.e., the best overall coherence while keeping the maximum number of topics with coherence bigger than 0.2) as the final model.

## 2.3. Topic and Paper Clustering

We calculated the inter-topic distance using the Hellinger metric over probabilities vectors—CalcHellingerDist() function—and we clustered topics by hierarchical clustering using Ward's method as the merge rule—hclust() function with ward.D option. We visualized the connection of the five top words for each topic with each field with an alluvial diagram, using the alluvial() function from the alluvial package (<https://github.com/mbojan/alluvial>).

The papers' clustering method was the same as the topic clustering one. We represented papers as point scattered over the first two dimensions of the multidimensional scaling of the distance matrix—cmdscale() function.

## 2.4. Paper Network Assembly

We converted the papers' distance matrix to a similarity matrix and then to an adjacency matrix, that was used to build a weighted, undirected paper network (graph\_from\_adjacency\_matrix() function from the iGraph package, [20]). To remove spurious connections, we deleted from the graph the edges whose weight was lower than 0.7 (i.e., the papers with low similarity). This filtering equates to consider 215 papers, or 37% of the data, as isolated.

## 2.5. Paper Network Visualization and Analyses

The final network contained 368 papers and was explored with the open source software Gephi [21]. The global network was displayed using the Fruchterman-Reingold force-directed layout algorithm [22], and the more populated components of the network were displayed using the ForceAtlas2 algorithm [23], which enhanced the visualization of clusters of papers. The community structure of the network, i.e., the clustering of nodes into modules, was found using the Louvain algorithm [24]. Finally, papers were ranked based on a degree index defined as the number of edges that are adjacent to the node plus the weight of these edges [25].

## 2.6. Extended Dataset Acquisition

We downloaded from Scopus all the results from the query “marine AND ecology AND economy” in every part of the document (22,061 documents). To download the abstracts, we queried the Scopus API using the rscopus package ([https://dev.elsevier.com/sc\\_apis.html](https://dev.elsevier.com/sc_apis.html), <https://github.com/muschellij2/rscopus>). We first removed the entries without DOI (2663 documents) and then used the DOIs of the remaining ones (19,398 documents) to query Scopus for full records. We extracted title, keywords, abstract, date of issue publication and EID (i.e., the Scopus identifier) from the downloaded object; as for the training dataset, we joined text columns together (title, keyword and abstract). Since the Scopus API only provided abstract for ScienceDirect indexed papers, we removed all the entries without

abstract, because there was not enough information to classify such entries with our methods. The final extended dataset included 5459 papers.

**Topic model fitting.** As done for the training test, we used the data as the training input for the creation of a DTM with both single words and diagrams. To screen for unwanted words, we calculated term frequency for the entire DTM, clean the data, and then use the predict() function to get topic distribution for new documents, using Gibbs sampling.

**Yearly trend display.** We selected for all papers in the extended dataset the most probable topic and the cluster it belongs. We then counted the times every cluster appeared every year (from 1970 to 2018) and used the count vector to build a bar graph.

### 2.7. Code

Code for all methods, except the Gephi analysis and visualization, is collected in two separated Rmarkdown files [available upon request].

## 3. Results and Discussion

The whole spectrum of the literature searched and reviewed in the present paper is shown in the PRISMA flow diagram in Figure 1. The most frequent words that establish the conceptual intersection between ecological and economic disciplines in the sea are shown in Tables 1 and 2, and reveal a prevalence of bigrams (respectively climate change, coral reefs, ecosystem services, and protected areas), with a strong, albeit small, contribution of fisheries issues—fisheries is among the top three words, and fish, fishing among the top ten.

**Table 1.** Frequency of top two-words terms in the analyzed dataset.

Term	TF
climate change	124
small scale	69
coral reefs	66
long term	58
fisheries management	57
marine resources	53
protected areas	49
ecosystem services	47
socio economic	44
fish species	40

TF stands for term frequency, and it is the number of times the term appears in the document-term matrix.

**Table 2.** Frequency of top one-word terms in the analyzed dataset.

Term	TF
marine	808
species	664
fisheries	521
coastal	516
economy	494
management	471
fish	435
economic	418
sea	354
fishing	324

TF stands for term frequency, and it is the number of times the term appears in the document-term matrix.

In the literature we explored, coastal systems accounted for 40% of the papers. This dominance is relevant and supports the view that coasts, plausibly for their prominent role in supporting a major part of the human population, are crucial targets of integrative socio-ecological approaches (e.g., [9,26]). Yet, only 9% of the analyzed papers related to both coasts and oceans. This segregation between aquatic science's disciplines has been noted already by Patterson and Glavovic [14].

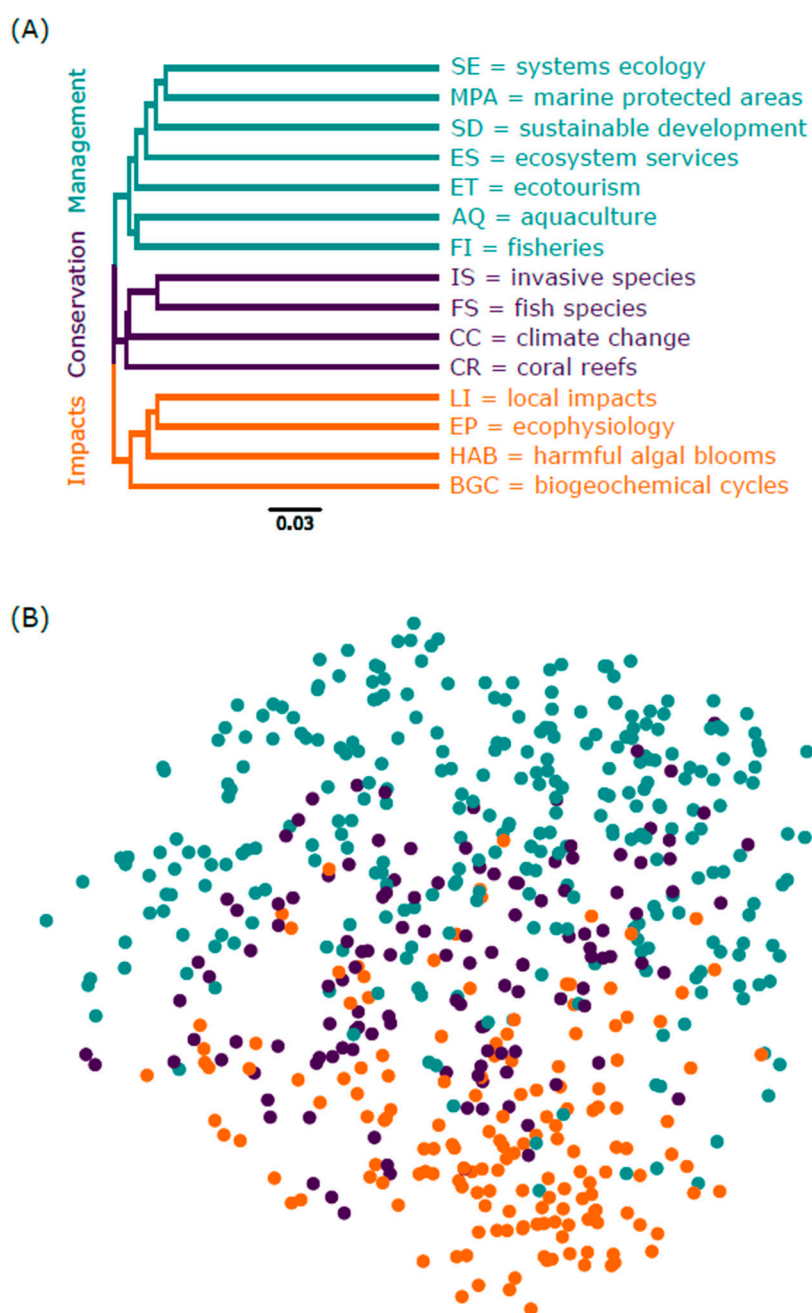
Eleven papers (2%) were associated with the word complexity, in two cases referring to multidisciplinary approaches (namely, [27,28]). The absence of the terms “complex system”, emergent property, nonlinear, irreversible, systemic, corroborate the view that the use of complex systems science to integrate ecological and economic disciplines in marine systems is still at its infancy [2].

We also detected that the papers integrating ecological and economic issues (n = 368) were distributed among a high number of different journals (n = 171) (see also Table S1). In addition, 78% of all papers were published in journals including just 1–2 of the above-mentioned papers. Therefore, if one excludes the limited contribution of major journals dealing with marine environmental sciences (i.e., 37 of these included about 22% of the total number of articles), the major portion of the papers under investigation originated from minor journals, and many of the latter were referring to local/national contexts, though distributed at global scale.

Fitting a fifteen-topics model on the training data produced topics aggregated in three fields (Table 3): management, impacts, and conservation. Each field includes a different number of topics (Figure 2A): we have fisheries (FI, a sector), aquaculture (AQ, a sector), systems ecology (SE, an approach), marine protected areas (MPA, an approach), sustainable development (SD, a concept), ecosystem services (ES, a concept), and ecotourism (ET, a sector) for the management field—invasive species (IS, a concept), fish species (FS, a concept), climate change (CC, a concept) and coral reefs (CR, a concept) for the conservation field—and local impacts (LI, a concept), ecophysiology (EP, a concept), harmful algal blooms (HAB, a concept) and biogeochemical cycles (BGC, a concept) for the impact field. In addition, topics included more concepts than approaches and sectors, suggesting that the inclusion of economic issues within marine ecology is still at a theoretical levels and applications are weakly diffused.

**Table 3.** Semantics and main characteristics of the topics identified from topic model analyses.

Code	Topic	Coherence	Prevalence	Top Five Terms
IS	invasive species	0.062	4.949	species, marine, sea, native, invasive
SE	systems ecology	0.068	10.59	social, environmental, fisheries, economic, research
BGC	biogeochemical cycles	0.15	5.657	oxygen, water, nitrogen, concentrations, bay
LI	local impacts	0.048	10.02	spatial, study, data, important, analysis
HAB	harmful algal blooms	0.33	5.884	blooms, algal, species, harmful, health
CR	coral reefs	0.426	3.846	coral, reefs, reef, coral reefs, mangrove
AQ	aquaculture	0.138	5.428	aquaculture, production, shrimp, farming, seaweed
CC	climate change	0.273	5.52	change, climate, climate change, ocean, impacts
FS	fish species	0.058	6.824	fish, species, populations, population, salmon
ET	ecotourism	0.113	4.277	tourism, economic, whale, million, industry
EP	ecophysiology	0.081	5.642	increased, growth, rate, effects, conditions
ES	ecosystem services	0.094	7.746	ecosystem, model, ecological, restoration, services
MPA	marine Protected Areas	0.069	7.331	management, marine, conservation, areas, resources
FI	Fisheries	0.186	8.007	fisheries, fishing, fishery, catch, management
SD	sustainable development	0.043	8.278	coastal, marine, development, environmental, water

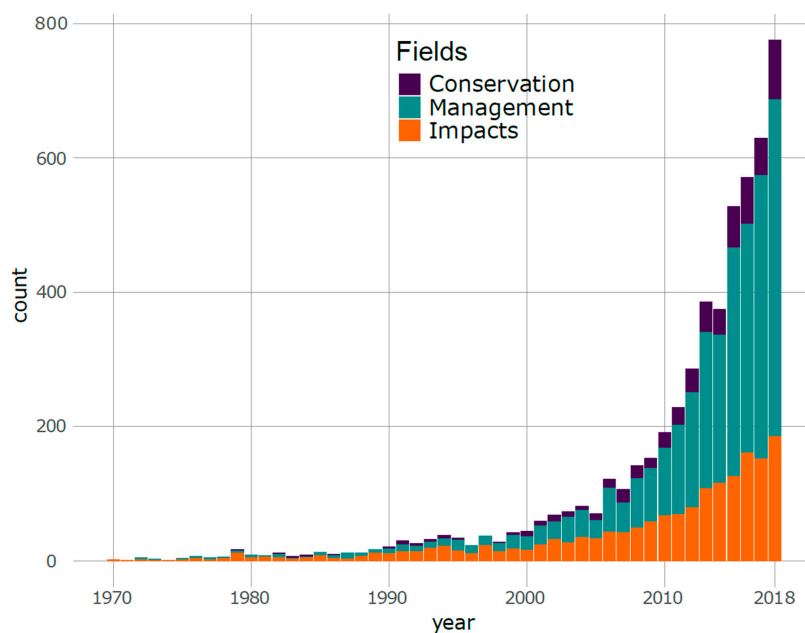


**Figure 2.** (A) Topics' clustering: Hierarchical clustering (Ward's method) of topics. The three resulting clusters were: management (light blue), conservation (dark violet), and impacts (orange). (B) Papers' clustering: metric multidimensional scaling based on papers' similarity in terms of shared topics. Color code as in Figure 2A.

However, we must notice that the distinction between fields pertaining to the integrated coastal management is not so strict (see Figure 2B), some topics are conceptually transversal and their computational inclusion in one specific field is apparently misleading (see Table 3). For instance, climate change and invasive species, which are usually associated to the evaluation of anthropogenic impacts, were included by the topic model analysis in the conservation field (instead of the impacts field) because they were more frequently detected in the literature dealing with protected habitats.

Our search also highlighted an exponentially growing interest in integrating ecological and economic issues during the last forty years, although this growth was mainly driven by the management field. This progress may stem from the disproportionate growth of purely economic studies in

comparison with those having a more ecological connotation, such as the ecosystem conservation and the monitoring of the impacts exerted by human activities (Figure 3).



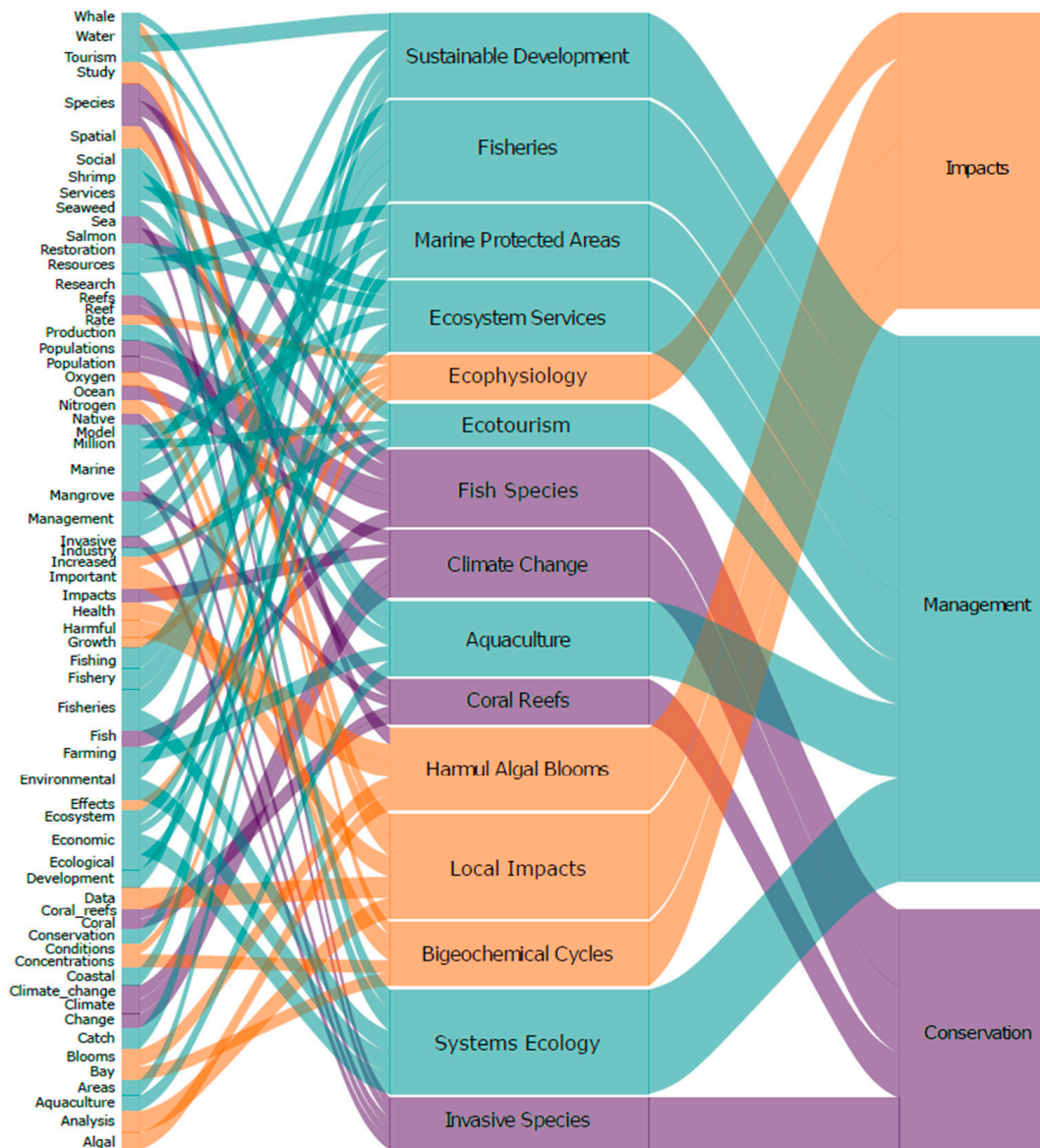
**Figure 3.** Scopus papers' trend: the fields trend over 40 years built with the 5459 papers from Scopus is shown. Papers are divided into different fields as for the Web of Science dataset.

The overall aggregation of words in topics and of topics in fields is shown in Figure 4. Among all, the four most distinct topics (i.e., over the third quartile, coherence  $> 0.186$ ) were coral reefs, harmful algal blooms, climate change, and fisheries. From the definition of probabilistic coherence, we can infer that these topics have a distinct identity because they share, with the other topics, the lowest number of associated words. Conversely, terms belonging to low-coherence topics (e.g., those belonging to the first quartile, coherence  $< 0.063$ ), like invasive, populations, spatial, and development, resulted as quite diffused in marine ecology/economy literature and aggregated weakly into specific topics.

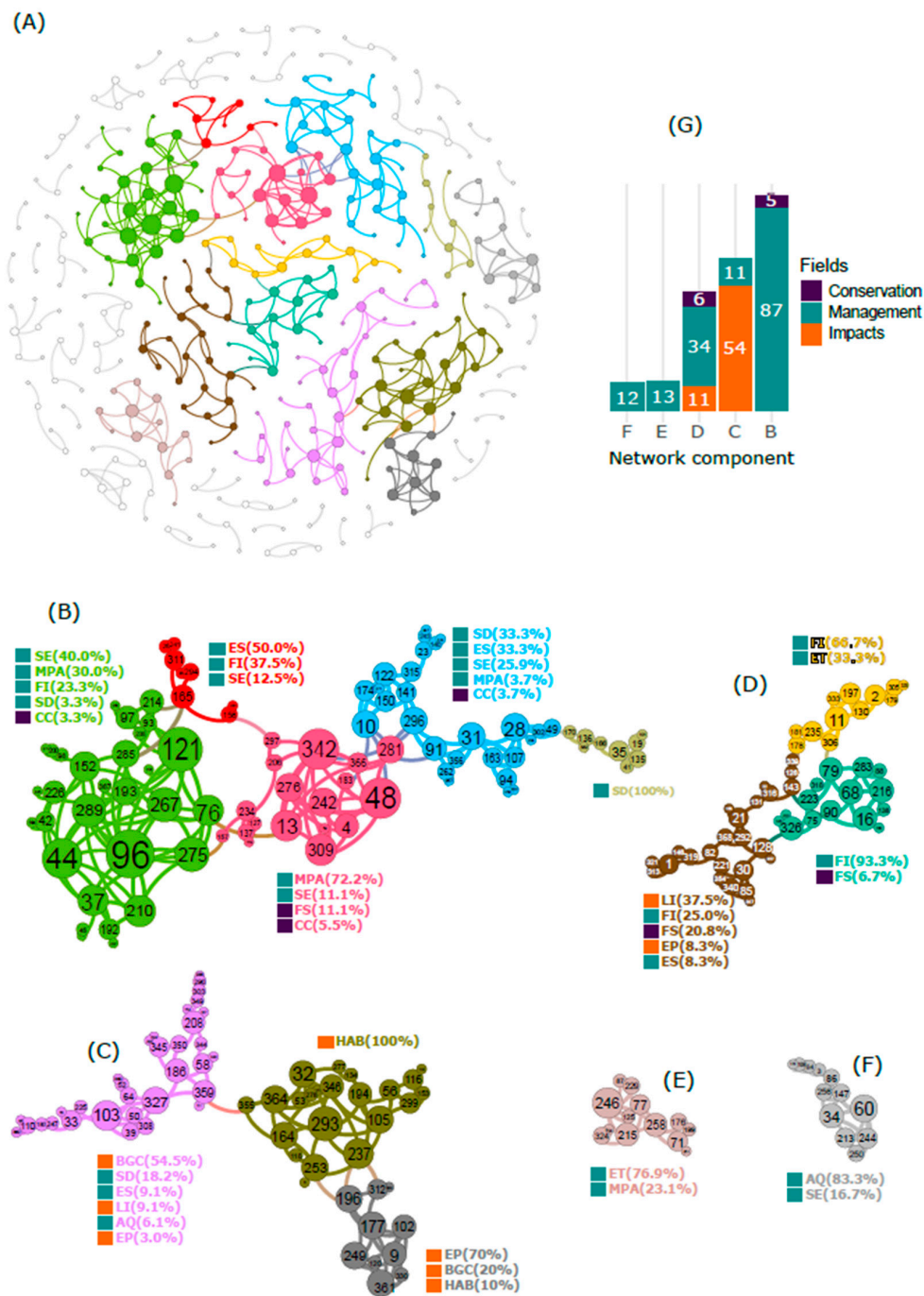
The information-flow network assembled using the similarity between papers based on shared words (Figure 5A) was characterized by a complex architecture comprising five principals, isolated components (Figure 5B–F). All but two of these components were organized in modules, and each module was made of a mixture of papers covering different topics (notice that a module is a group of papers for which the intra-group relatedness is higher than the relation with other groups).

In the following paragraphs and sections, the integration pathways between ecological and economic issues in the sea are described in details, by examining those key publications providing connections between topics and fields. Papers included by topic modelling in the information-flow network are highlighted hereafter by the code that appears in Figure 5 (and in Table S1). These papers are also linked to their specific reference, as it appears in the references list appended at the end of this review. All the other papers discussed and cited from here onwards are not included in the network in Figure 5, since they were not identified by the algorithms used in the topic model analyses.





**Figure 4.** Alluvial diagram: the flow diagram shows on the left the most prominent words that compose each topic (shown in the center), and the aggregation of the topics into the three fields on the right. The dimension of rectangles on the right is proportional to the fields’ prevalence. Colors are the same as in Figure 2.



**Figure 5.** (A) Paper network, or information-flow network, linking the papers with the highest reciprocal similarity (i.e., 368 papers) as visualized using the open source software Gephi [21]. Nodes represent papers, links reflect shared topics, and link weight represents the fraction of shared topics between neighboring nodes. Node dimension is proportional to node’s degree (i.e., the prominence of the node defined based on the amount of information it shared with its neighbors). The colored modules (i.e., sub-groups of more reciprocally related papers) are those including more than eight papers. (B–F) Network components: five principal components of the network in (A). The number in each network node is the paper code as connected to the specific reference reported in Table S1. Each component includes one or more modules colored as in (A). For each module, the percentage of the topic within the module and the topic’s field are indicated. (G) Network’s composition: fields and numbers of papers for each field included in the five principal network components. The colors are the same as in Figures 2 and 3.

### 3.1. Marine Protection as a Bridge Between Ecological and Economic Issues within the Integrated Coastal Management

The largest component in the information flow network included five modules of various size, 92 papers in total, that covered seven topics (Figure 5B). This component was strongly associated with the management field, and four out of five modules aggregated environmental studies within marine protected areas. Overall, the papers in this component were related to: (i) the management of small-scale fisheries, especially those in the context of marine protected areas, (ii) environmental science issues, and (iii) sustainable development studies, mainly related to coastal water quality. A small number of papers dealt with conservation concepts, such as climate change effects on marine habitats and endangered fish species.

Within the above-mentioned component (Figure 5B), the biggest module (30 papers, in green) was composed mostly by systems-ecology studies, management of marine protected areas and fisheries (in order of prominence). The second in rank (27 papers, in blue) focused on sustainable development, ecosystem services, and systems ecology. Marine protected areas dominated the central module (18 papers, bright red). One peripheral module (nine papers, in ochre) included only papers related to sustainable development. The smallest module (eight papers, in red) aggregated mainly papers associated with ecosystem services and fisheries. Green and blue modules were the most 'systemic' ones (i.e., they encompassed multiple standpoints), in fact, bright red and ochre modules were more specifically dealing with marine protected areas and sustainable development, respectively. The red module was in-between and it was fundamental in guaranteeing the flow of information in the network component under discussion.

Based on the papers' network in Figure 5B, the combination of ecological and economic issues is largely pursued in the context of marine protected areas (MPA). However, we must consider that inter-module connections are not as frequent as expected, and few connecting papers act as gateways, i.e., they establish multiple connections with parent papers (present in the same module) and sustain some links with papers belonging to other modules.

More specifically, papers associated with large-scale, coastal fisheries management and included in the green module connected to papers associated with socio-ecological issues that were included in the red and bright-red modules ([29], paper #214; [30], p. 285; [31], p.165). Whereas papers discussing small-scale fisheries management linked green to bright-red modules ([32], p. 76; [33], p. 275; [34], p. 157; [35], p. 13). In turn, a single connection between red and bright-red modules emerged, between papers discussing marine conservation issues ([36], p. 158; [37], p. 297).

The bright red module was strongly connected to the blue one by four papers involved in multiple associations, mostly related to coastal planning (paper #48, [38]; #183, [39]; #281, [40]). The sole exception was a best-practice commentary aimed at involving citizens in environmental management ([41], p. 342). The blue module pointed to decision-related issues, such as marine governance ([42], p. 10), governance of plastic pollution ([43], p. 91), and visions for ecosystem-based management ([44], p. 296). The ochre module was connected to the blue module by a single connection, linked to water-quality management at a national level ([45], p. 49; [46], p. 170).

The analyses on the first, major component of the information-flow network (Figure 5B) leads to the consideration that the strongest trans-disciplinary integration in the integrated coastal management is realized in the management of protected areas. For instance, this observation reflects the tendency towards integration pursued in the marine spatial planning, a sustainability approach that is mainly focused on the coasts (see, e.g., [26,47]). To this respect, marine protection is a critical asset of suitable plans for blue cities and it is plausibly capable of bringing ecologically-sustainable economic growth under different perspectives.

Being more accessible to both ecologists and economists, MPA, in general, can provide fundamental case studies to improve knowledge-exchange with the aim of ameliorating ICM. In addition, MPA are more and more seen as a positive way to combine biological conservation and recreative activities, e.g.,

by establishing marine parks in which to enhance the public engagement with ecological issues and, at the same time, increase the overall value of the waterfront of urbanized areas [48].

### 3.2. The Isolation of Harmful Algal Blooms: Weak Perception of the Associated Economic Risks?

The second largest component in the paper network (65 papers) included three modules (violet, dark green, dark grey nodes, Figure 5C) and aggregated a considerable number (80%) of papers associated with the impact field, and only a small fraction of papers (20%) associated with management. This stands as the only exception to the predominance of the management field among the different network components (Figure 5G). The most representative topics of the network-component under examination were harmful algal blooms and biogeochemical cycles (HAB and BGC), mainly including studies about phytoplankton.

The largest module of the above-mentioned network-component (33 papers, in violet) was also the largest module of the entire network (Figure 5C). This module aggregated papers related to management and ecosystem approaches, such as those focusing on biogeochemical fluxes, the progress of sustainable development goals, and assessment of ecosystem services. The second largest module (22 papers, in dark green) only included papers related to HAB. Therein, the most central paper was a description of methods to detect microalgae that impact human health ([49], p. 293): this study emphasizes the importance of advancing the environmental monitoring to mitigate the impact of HAB bio-hazards on the economy of marine food production. Thus, although implicitly, it calls for better inclusion of micro-organisms surveillance in ICM. The third and smallest module (10 papers, in dark grey) aggregated mostly (70%) ecophysiological papers (EP) associated to microbial species, with small contributions from BGC (20%) and HAB (10%) topics.

The three modules of the above-mentioned network component formed a chain of information-flow, with the dark green module acting as a conceptual bridge between the violet and dark-grey ones (Figure 5C). On the one hand, only two papers, which dealt with environmental contamination and the bacterial role in the nutrient cycle ([50], p. 359 and [51], p. 355, respectively), provided a connection between violet and dark-green modules. Conversely, the connection between dark green and dark-grey modules was established by three papers, which pertained to: (i) laboratory-based experiments on microalgal growth and interaction with other organisms (#237, [52]), (ii) in-situ observations of plankton communities in concomitance with HAB (#253, [53]; #312, [54]), and (iii) the dynamics of algal toxins production under nutrient limitation (#196, [55]).

As a general consideration, the above-mentioned network component appears as highly segregated from the other ones, which, instead, deal with several typologies of economic activities (compare Figures 5B and 5C): this feature may remark, at the same time, the weak integration of plankton studies in ICM [56,57], and the still not-fully perceived economic risks associated with the proliferation of harmful algal blooms in coastal systems (see, e.g., [58]).

### 3.3. The Mature Socio-Ecologic Fingerprint of the Management of Commercial Fishery

The third largest component (51 papers) of the information-flow network included three modules (Figure 5D), all strongly associated with the management field and mostly linked to large-scale fisheries. Overall, this component was characterized by evenly connected, structured modules, gravitating around the same topic. Notwithstanding their strong association with fisheries, each module maintained a distinct identity: namely, a broad, systemic module aggregated a wide range of papers (brown), and two more specific modules dealt with the general management of fisheries (dark green) and the repercussion of ecotourism over fisheries (yellow), respectively.

In more specific terms, the largest module therein (24 papers, in brown, Figure 5D), showed the biggest heterogeneity among all the other modules, with 46% of the papers belonging to the impacts field, 33% belonging to management, and 21% belonging to conservation. Those papers that deal with local, somewhat unusual, case-studies occupy keystone positions, and guarantee the flux of information within the network component. Among all, we notice: (i) a study exploring the value of

local knowledge in designing the regulation of recreational fisheries (paper #1, [59]), and (ii) a paper dealing with fishing economies in ancient times and focusing on traded fish-goods and typologies of recipients to bear them (#21, [60]). Taken together, these observations suggest the value of historical research in understanding the shaping forces of modern maritime economies.

The second module in the above-mentioned network-component (15 nodes, in dark green, Figure 5D) aggregated papers associated with large-scale fisheries, and the most central paper therein dealt with the socio-economic impacts of bycatch (#216, [61]). The smallest module of the component (12 nodes, in yellow) included a copious fraction (33%) of papers pertaining to ecotourism (ET topic), suggesting the important role played by recreational activities in promoting sustainable fisheries. For instance, the most central node in this module (dark green, dark green, Figure 5D) was a study focusing on the potential and realized economic impacts of recreational fishery in Algeria territorial waters (#11, [62]). To remark the integration between recreational and commercial activities in fishery science, the brown and dark green modules linked twice, and one link established between one paper presenting a stock-assessment for a commercially-exploited sea urchin and one paper about recreational catches, both of them focusing on USA coasts (#326, [63]; #128, [64]) (Figure 5D).

Finally, the yellow module was connected directly to the core of the dark green one by two papers (Figure 5D): one of these provided an economic comparison between commercial and recreational fisheries in Namibia (#306, [65]) and a second paper dealt with the impact of bycatch on fish stocks (#79, [66]). The connection of the brown module to the yellow one was achieved through a chain of connections drawn by management studies at local level, from the Indian Ocean (#126, [67]) to the Black Sea (#339, [68]) and the African coasts of the Atlantic Ocean (#178, [69]). As a general consideration, local and specific case studies can exert a high impact on the exchange of information in the fishery management network (Figure 5D) and may be inspiring good ICM practices in other geographical contexts.

All these features, collectively, indicate the integrative fashion of fishery science, which shows a higher degree of maturity when compared with other disciplinary ambits. This maturity has been plausibly conferred by the historically established relationship between population ecology approaches and economic exploitation of fish. As a part of ICM, the fishery management can be likely seen as a proficient proof of concept, useful to provide conceptual pipelines to design management practices at the ecosystem level.

#### 3.4. *Inclusive Economy Is Markedly Peripheral Within the Coastal Management*

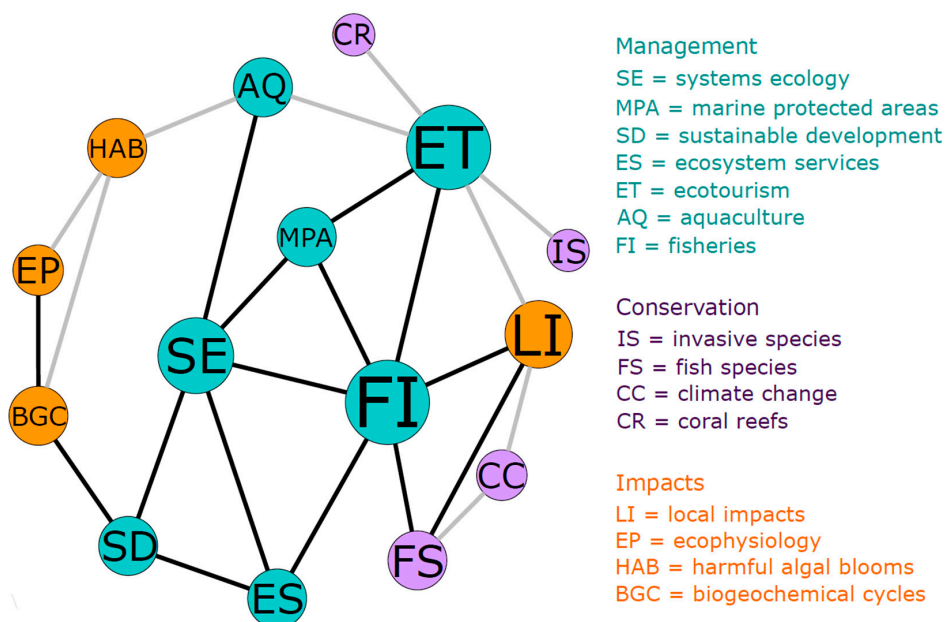
The last two and smallest components in the information-flow network were exclusively related to the marine/maritime sectors ecotourism and aquaculture (Figure 5E,F, respectively). The first included a relevant fraction of papers relating to marine protected areas, and the most connected paper therein discussed the role of iconic shark species in Polynesia—which can be seen, by the local population, as either business partners (i.e., attraction for commercially-exploitable recreational activities) or food resources (#246, [70]). Concerning the aquaculture network (Figure 5F), the most connected papers were two reviews, one about advancements in seaweed culturing (#60, [71]) and one regarding the use of microalgae to enhance aquaculture sustainability (#34, [72]). This observation suggests that research and development in aquaculture are more focused on primary producers than on consumers and higher organisms, such as fish and invertebrates.

Ecotourism and aquaculture are evidently apart from the core of the information-flow network, which appears mainly focused on the (tentatively integrated) management of marine protected areas, at the local scale, and fisheries, at the regional scale (compare Figure 5E,F with Figure 5B,D). The isolation of ecotourism and aquaculture in the framework of integrated coastal management is relevant, since the above-mentioned sectors are among the most economically-inclusive ones, i.e., they promote economic growth fairly across society by creating job opportunities for specific territories, and they could play as a key asset for marine sustainability and coastal resilience as well.

The above-mentioned segregation may stem from several factors. Based on the literature we explored, ecologically-sustainable tourism is weakly linked to environmental conservation. In this context, the virtuous economic exploitation of iconic animals, such as sharks, is becoming a key asset of developing economies (see, e.g., [73–75]), and this practice may provide a link between management and conservation, within the framework of sustainable tourism [76]. As for aquaculture, the isolation of this sector is due to the fact that the pertinent investigations are more focused on the productive processes, and the ecological and economic sustainability are not key issues. Nonetheless, the link between aquaculture investigation and conservation is already there (see, e.g., the interaction between marine farming and seagrass [77,78]) and this link may be representing the base on which to build integrative, ecological/economic studies in the frame of coastal management.

### 3.5. Road-Mapping the Coastal Management: Systems Ecology and Citizen Science as Potential Integration Nodes

The main finding of our study is the weak systemic connotation in the integrated coastal management, as the conservation of coastal ecosystems and the evaluation of anthropogenic impacts are weakly integrated with the management of economic sectors. A possible roadmap to ameliorate this condition and channel integrative ICM practices is shown in Figure 6.



**Figure 6.** A roadmap for the integrated coastal management. This simplified information-flow-network schematizes the conceptual integration between concepts, practices and sectors (i.e., topics) that contribute to the integrative coastal management. Topics' coding as in Table 3. Black links are the most prominent ones among those found in our analyses, grey links are the weaker links, whose improvement can however facilitate the integration among different ICM fields. Node dimension is proportional to node's degree (i.e., the prominence of the node defined based on the amount of information it shared with its neighbors). Colors are as in Figures 2 and 3.

A central role in the information-flow that we draw from the reviewed literature is played by systems ecology (see SE in Figures 5B and 6), a particular approach that applies general systems theory to ecological problems pertaining to both pristine and impacted ecosystems [79]. From our analyses, systems ecology already conveys solid knowledge transfer between environmental conservation, evaluation of anthropogenic impacts and management of habitat and natural resources, such as fish stocks. Nonetheless, systems ecology is still weakly linked to both (i) conservation studies dealing with biodiversity and the climate change effects (IS, CR, FS, CC in Figure 6), and (ii) biogeochemical

investigation, such as those about the nutrient cycling and plankton blooms (HAB, EP, BGC, LI in Figure 6).

The first gap may be filled by reinforcing the information flow throughout MPA, also by exploiting the engagement of citizens (e.g., via recreational activities and ecotourism), as already discussed by some authors so far (e.g., [80,81]). Public engagement may be helpful in integrating ICM and some crucial but neglected issues in the information-flow network, such as invasive species, and iconic environments like coral reefs (Figure 6). Furthermore, biogeochemical investigations can be integrated within ICM by exploiting systems-ecology approaches applied to pelagic environments, e.g., the so-called augmented marine/ocean observatories that are being established along the coasts to expand the resolution of environmental monitoring [82,83].

Systems ecology is also weakly linked to studies focusing on water quality (HAB, EP, BGC, Figure 6), with the only strong but indirect link provided by the research on sustainable development (SD). It is not clear whether or not the above-mentioned link is enough to sustain the overall information flow. However, one may notice that the link between studies related to harmful microalgae and aquaculture management (HAB and AQ in Figure 6) should be urgently improved, because toxic microbes represent a tangible threat to seafood production.

To this latter respect, the presence of Long Term Ecological Research sites (LTER, [84]) in the waterfront of urbanized areas hosting open-water aquacultures, such as in the Gulf of Naples (Naples, Italy, [85]), guarantees the collection of data useful to track the passive transportation of HAB species, their demography and also the contribution of these organisms to the aquatic food webs [86–88]. These data can feed systems ecology by allowing the integration of ecosystem modelling into aquaculture management [89]. Also, high-resolution data could be easily complemented with citizen-science-based monitoring focusing on irregularly occurring biohazards, such as toxic microalgal blooms [90].

Environmental protection is also a crucial element in our roadmap (Figure 6), and this consideration is in agreement with previous studies [91]. We also noticed that marine protection is highly linked to ecotourism, but the link between ecotourism and management of the coasts appears as relatively weak (Figures 5 and 6). Again, this gap can be reinforced by developing citizen-science-based monitoring programs, as already experimented for marine invasive species in generic coastal environment, i.e., which are not under protection [92,93]. Responsible and scientifically-engaged tourism can be a way to improve sustainable development, e.g., in line with the principles of the Blue Growth strategy by the European Union (EU-BG), which envisions an inclusive marine economy based on sustainability criteria and limiting the mere financial exploitation of the marine ecosystems [94].

Ecological tourism is a transversal sector, being linked to both small-scale and commercial fisheries, the latter are strongly connected to ecosystem-based management (i.e., ecosystem services' evaluation, investigation of fish species, local impacts due to climate change, etc.) thus establishing preferential information-flows between ecological, economic and social contexts (Figure 6). This aspect could also profitably match the need for a higher integration between marine science and the general public, which scientists also perceive as urgent [95]. In this context, socially inclusive plans for the institution of marine protected areas can represent suitable integrative practices, which have been already run, e.g., along the Brazilian coasts [96].

In addition, tourism is the most profitable and expanding economic sector in EU-BG (see [https://ec.europa.eu/maritimeaffairs/policy/blue\\_growth\\_en](https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en)): if its integration with environmental management is highly desirable, the potential synergy between ecotourism and productive sectors, such as fisheries and aquaculture could be profitable too. For instance, fishing tourism is already run along the Italian coasts, with citizens being engaged with professional but artisanal fishery to catch the fish they eat on board [97]. Furthermore, touristic trails conducted by scientist are becoming more and more frequent in different environmental contexts (see, e.g., [98]): by allowing the informal encounter between scientists and the general public, these initiatives allow informing people on nature's role in the provision of goods and services, and they also pave the way to citizen science initiatives.

#### 4. Conclusions

In synthesis, based on the systematic literature review presented herein, the integrative coastal management is more likely capable to drive sustainability when accomplishing the subsequent aims indicated in our ‘roadmap’:

- (i) Exploiting the utility of marine protection as a bridge between ecological and economic concepts and approaches, and between ecological economics sectors,
- (ii) Improving the role of systems ecology as an integration node, in the frame of inter-disciplinary scientific initiatives,
- (iii) Complementing systems ecology with citizen science, in the frame of inclusive economic initiatives, such as ecotourism.

The protection of coastal habitats and natural resources deriving from them is at the base of the sustainable use of nature, and their governance requires both scientific and economic innovations, which should be not only introduced, but also integrated, under the umbrella of indispensable political innovations (e.g., [99]). While the politically-driven sustainability is still biased by a vision dominated by the purely short-term exploitation of nature (see, e.g., the debate about the sustainability of Blue Growth [94,100]), the economic value of marine biodiversity in terms of good and services, provided over the long-term, is immense [2,101].

The integrations of ecological and economic ambits, in order to be realized, should be supported by the effective exchange of knowledge among the multifaceted components of our societies. Such an effort should be taken by both ecologists and economists, along with sociologists, e.g., historians of science, humanists, communicators, etc., who can play as fundamental integrating actors, i.e., by providing scientists with languages suitable for the information of the general public (see, e.g., [102]). To this respect, the present study strongly calls for further assessments of the level of integration between the ecological, economic, and social dimensions, in the overall framework of coastal management.

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/2071-1050/11/16/4393/s1>, Table S1 (excel file): Papers database for the information-flow network.

**Author Contributions:** D.D. conceptualized and supervised research; L.R. assembled the dataset and sorted literature with the contribution of D.D.; B.H.M. carried out statistical analyses with the contribution of L.R.; D.D. and B.H.M. visualized data; D.D. drafted the manuscript; all authors contributed to the last version of the manuscript.

**Funding:** This research received no external funding. B.H.M. post-doc project is supported by the project “Sperimentazioni pilota finalizzate al Restauro Ambientale e Balneabilità del SIN Bagnoli-Coroglio (ABBaCo)”, funded by the Italian Ministry for Education, University and Research and Comitato Interministeriale di Programmazione Economica (CIPE, grant number C62F16000170001).

**Acknowledgments:** We acknowledged four anonymous reviewers for their helpful comments, which remarkably drove the production of a mature presentation of this study, and Wiebe H.C.F. Kooistra (Stazione Zoologica Anton Dohrn, Naples, Italy, and EMBRC Italy) for reading and commenting the final version of the paper. This paper is the contribution #1 of the program SEEMS—Systems Ecology and Evolution for Marine Sustainability.

**Conflicts of Interest:** The authors declare no conflict of interest.

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