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A Scientometric Assessment of Research on the Use of Bioeconomic Modeling in Fisheries

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Abstract

This research has been undertaken to analyze the research trends in bioeconomic modeling and has presented the basic bioeconomic models which are being applied in different areas of fisheries. A subscription-based database -viz Web of Science (WoS) was used to retrieve literature regarding bioeconomic models in fisheries from the year 1998-2021. A total of 1100 articles were subjected to data analysis using MS-Excel and Power Bi. The scientometric assessment result showed that there is a positive correlation between years and the number of publications. It also provided information on leading authors on international and national levels and gave insights on country-wise and highly cited publications on bioeconomic modeling in fisheries. The journal Fisheries Research carried the maximum number of research papers (88), followed by International Council for the Exploration of the Sea Journal of Marine Science (51). The study also identified and categorized the basic bioeconomic models with their application in various areas of fisheries for future research guidance. The study is envisaged to add to the repository of knowledge and highlight the need and importance of using bioeconomic modeling in fisheries for sustainable fisheries management and generating an evidence based policy framework.

Keywords: Bioeconomic models, Fisheries, Web of science, Scientometrics

JEL Classification: Q5, Q22, Q57

Introduction

Fish and fisheries are an integral part of most societies and make important contributions to the economy and prosperity in many countries and areas (Cochrane, 2009). The total world fisheries and aquaculture production showed a significant growth of 42% from 2000 to 2018, reaching a record of 179 million tonnes in 2018. A large number of species are harvested every year, with the quantities and specific species varying from country to country (Anonymous, 2020a). The fisheries and aquaculture sector are a major source of employment; it has been estimated that 59.5 million people were engaged in the primary sector of fisheries and aquaculture (Anonymous, 2020a). With the expanding growth in the fisheries sector managing the fisheries resources for their contribution to food security, employment, and economic development are of paramount importance, which requires long-run management plans and evidence-based policies to address the sector's issues and threats. In the 21st century, unequal distribution of population and income growth will cause an increasing stress on fisheries resources (Sanchirico and Wilen, 2001). The goal of fisheries managers towards fisheries management is to provide sustainable biological, social, and economic benefits from renewable aquatic resources (Habib *et al,* 2014). In developing countries, improved fisheries management, investment in sustainable aquaculture, and protection of key habitats will restore ocean productivity and return benefits to billions by ensuring future growth, food security, and jobs for coastal communities (Anonymous, 2021b). In places where fisheries management is not in place or is ineffective, the status of fish stocks is poor and deteriorating. (Anonymous, 2020a). For many years, the main objective of fishery management was

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to maximize the yield taken from a fishery without compromising future catches. But now, fisheries science management objectives are increasingly diverse, and the attempts to manage and conserve fisheries are based on the scientific understanding of fishers and the fished ecosystem (Kar and Matsuda*,* 2006; Clark, 2006). At present, many fishery scientists are directing their research interest towards the economic and social concerns of fisheries, aquaculture, and its management. Viewed in this way, the application of Bioeconomic models in fisheries resource management plays a prominent role. Bioeconomics is a subfield spanning ecology, economics, and applied math and is concerned with models that integrate both population dynamics and economic value (Conrad and Smith, 2012). Bioeconomic modeling refers to the use of mathematical techniques to model the performance of biological production systems that are subjected to economic, biological, and technical constraints (Allen *et al,* 1984; Anderson and Seijo, 2010). In compliance with the above-quoted justification and its importance, we have conducted a scientometric assessment on bioeconomic modeling in fisheries at a global level. The aim of this aspect of the study was double-edged: 1. This paper assists in knowing about the research trends, authors, highly cited publications, and countries contributing to the publications of bioeconomic modeling in fisheries. 2. The findings of this study will help a researcher working on modeling, to know about the bioeconomic models and their applications in the respective fields.

The paper is structured as follows: The first part of the paper provides with the results of the scientometric assessment of bioeconomic modeling in fisheries, and the application of bioeconomic models in different areas of fisheries is listed in the second part.

Data Sources and Methodology

Literature on Bioeconomic models was piled up from subscription-based database -viz Web of Science (WoS) for the period of 1998-2021. Web of Science is an online subscription-based scientific citation indexing service maintained by Clarivate Analytics United States that provides a comprehensive citation search. It gives access to multiple databases that reference cross-disciplinary research, which allows for in-depth exploration of specialized sub-fields within an academic or scientific discipline. The publication search was conducted in WoS deploying the keywords "Bioeconomic modeling", "Bioeconomic model", "Age-structured model", "Dynamic bioeconomic model", "Static bioeconomic model", and "fisheries", in "TOPIC" field, which covers title, abstract, authors, first author affiliation and keywords of each publication. After collection and compilation, the duplicate number of publications was identified and removed. A total of 1100 publications were extracted and scanned for quantitative assessment of scientometric indicators like research trend, authors, citations, Journals, and countries publishing on "Bioeconomic modeling in Fisheries". The tools used for the scientometric assessment were MS-Excel and Power Bi for data visualization. Along with this, the open-source word cloud generator tool 'Word It Out' was used to create the word cloud by assessing the popular themes covered in the published scientific literature.

Results and Discussion

Number of publications on bioeconomic modeling in fisheries

The analysis of this study ascertained that number of articles and total year of publications are positively correlated with each other. The graph (Figure 1) represents that the number of publications on bioeconomic modeling in fisheries have increased gradually from 1998-2021. The number of publications at the starting year 1998 was 18, contributing 1.64% of the total publications. The initial rising trend was observed in 2008 with 50 publications (4.55%). Across all the 24 years of publications, 2017 has the highest number of publications (89), accounting for 8.09%. To substantiate this increase, according to the 2020 the State of World Fisheries and Aquaculture (SOFIA) report published by FAO, the biologically sustainable stock levels have decreased from 90% to 65.8% from the year 1974-2018, and also it is estimated that 35 percent of the global harvest is either lost or wasted every year in fisheries and aquaculture. Hence, there is a chance that these reasons will escalate the research interest and number of studies in bioeconomic modeling in fisheries in the forthcoming years will surge. There is a need to address the issues plaguing fisheries stock management globally.

A trend analysis was done to estimate the patterns of growth in the no. of publications over years (Figure 2). The trend analysis revealed that time is explaining 90% of variation in the no. of publications with an exponential growth rate of 8% indicating the growing

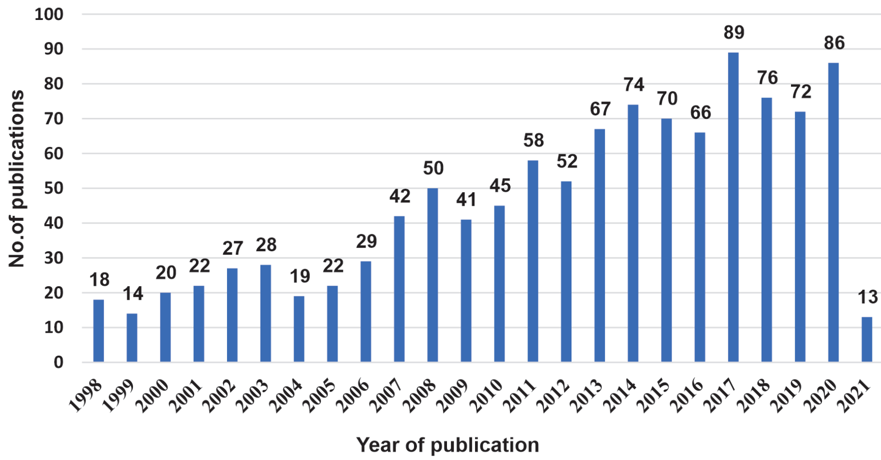

Figure 1. Number of publications on bioeconomic modeling in fisheries

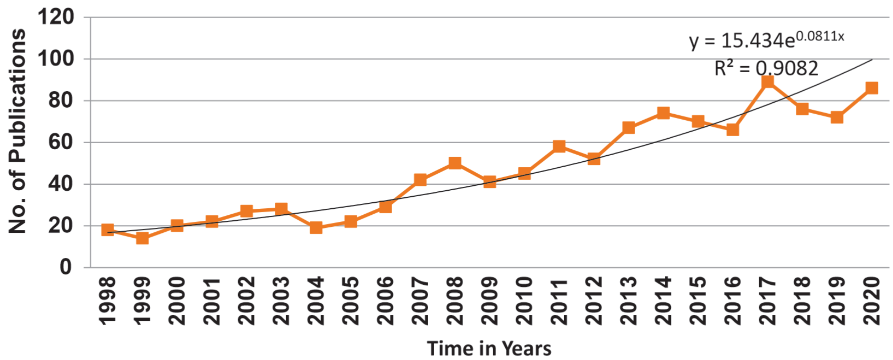

Figure 2. Trends in number of publications

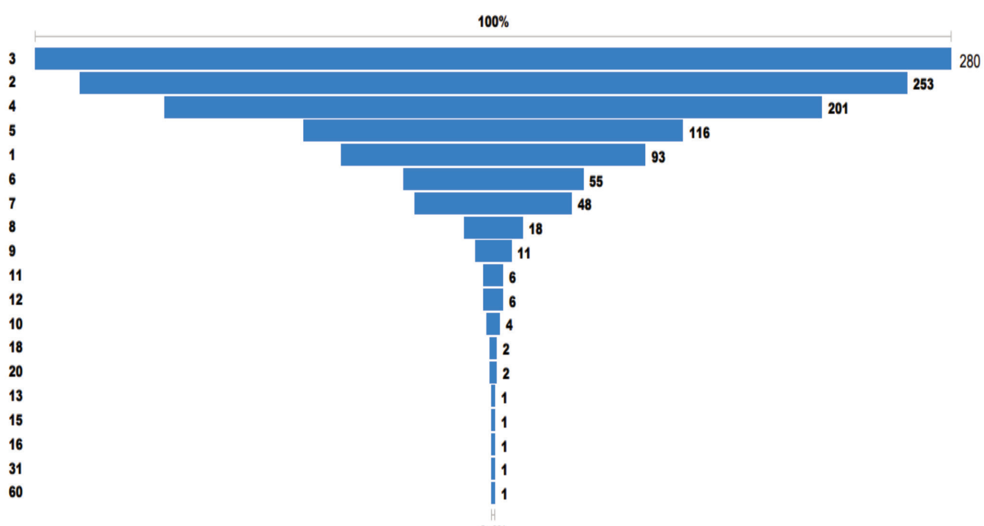

Figure 3. Number of authors in publications

interest in the subject considering its importance.

Number of authors in publications

The findings of the author's count analysis revealed that maximum number of articles (280) were authored by three authors while 253 articles which were authored by two authors (Figure 3). Further a total of 60 authors have authored a single paper on integrated ecological-economic fisheries models.

Top 10 cited publications

One of the important indicators in scientometric assessment is citation analysis. Citation analysis measures the relative importance or impact of an author, an article or a publication by counting the number of times that author, article, or publication has been cited by other works. The citation analysis of this study revealed that the article published in 2000 titled "Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries" authored by Pauly, *et al*, 2000 has received the highest citation of 642 and per year citation of around 29. It was also found that C Costello and J.M Elliott have published the next topmost cited publications on bioeconomic modeling in fisheries (Table 1).

Top countries publishing on bioeconomic modeling in fisheries

The results of the country-wise publications indicated that the USA ranked first with 245 publications in bioeconomic modeling in fisheries, followed by Australia (86), Mexico (75), China (70), and France (62) (Figure 4). The study noted that most of the literature published by United States of America (USA) focused on marine protected areas (MPA) as MPA covers 26% of USA waters and also the country has established nearly 1000 MPA's to protect the fisheries resources. The study found that India is lagging behind developed countries in the number of publications on bioeconomic modeling in fisheries. The number of publications published by India from 1998-2020 was merely 39. However, India's goal towards sustainable development and a blue economy can pave the way for an increase in research in this subject field in near future.

Top 10 journals publishing on bioeconomic modeling in fisheries

The top 10 journals which have published on bioeconomic modeling in fisheries are listed in the descending order (in Table 2). Fisheries Research- a peer-reviewed academic journal published by Elsevier, is the journal with the highest number of publications (88) on bioeconomic modeling in fisheries. The journal provides an international forum for the publication of papers in the areas of fisheries science, fishing technology, fisheries management, and relevant socioeconomics. ICES Journal of Marine Science is at second position on the list with 51 numbers of publications. This journal focuses on the articles that contribute to our understanding of marine ecosystems and the impact of human activities on them. The journal with the highest impact factor in the list is Ecological Economics which is concerned with the publications emphasizing on the integration of ecosystem and economy.

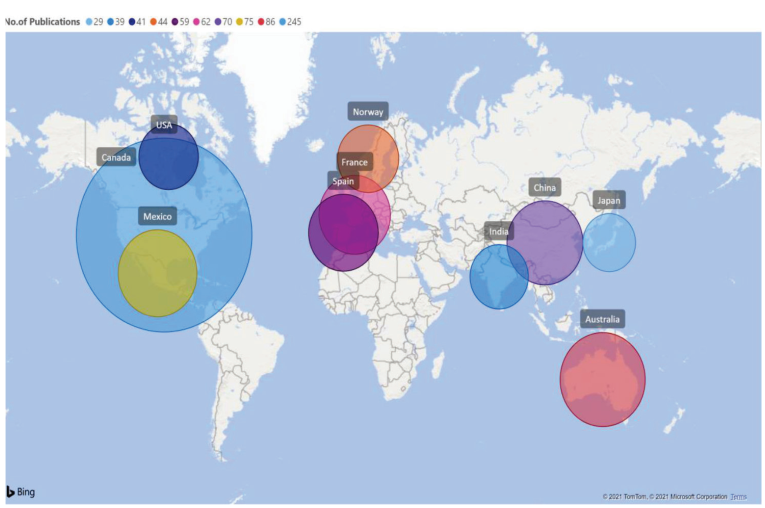

Figure 4. Top countries publishing on bioeconomic modeling in fisheries

Table 1. Top 10 cited publications

Article	Authors	Journal	Year	Cites	Per year cites	Journal Impact	First author affiliation
Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries	Pauly,D, Christensen,Walters, C	ICES Journal of Marine Science	2000	642	29.18	3.188	University of British Columbia - Vancouver
Global fishery prospects under contrasting management regimes	Costello, C; Ovando, D; Clavelle, T; Strauss, CK; Hilborn, R; Melnychuk, MC; Branch, TA; Gaines, SD; Cabral, RB; Rader, DN; Leland, A	Proceedings of the National Academy of Sciences of the United States of America	2016	260	43.33	9.412	University of California, Santa Barbara
Temperature requirements of Atlantic salmon Salmo salar, brown trout Salmo trutta and Arctic charr Salvelinus alpinus: predicting the effects of climate change	Elliott, J. M.; Elliott, J. A.	Journal of Fish Biology	2010	249	20.75	1.495	Freshwater Biological Association, U.K.
Modelling fish growth: multi-model inference as a better alternative to a priori using von Bertalanffy equation	Katsanevakis, S; Maravelias, CD	Fish and fisheries	2008	164	11.71	6.785	Institute of Marine Biological Resources, Hellenic Centre for Marine Research, Greece
BUGS in Bayesian stock assessments	Meyer, R; Millar, RB	Canadian Journal of Fisheries and Aquatic Sciences	1998	136	5.91	2.849	University of Auckland, New Zealand
Valuing the environment as input: review of applications to mangrove-fishery linkages	Barbier, EB	Ecological Economics	2000	129	5.86	4.482	University of York, Heslington, UK
Diversity and complexity of angler behaviour drive socially optimal input and output regulations in a bioeconomic recreational-fisheries model	Johnston, FD; Arlinghaus, R; Dieckmann, U	Canadian Journal of Fisheries and Aquatic Sciences	2010	122	10.17	2.849	University of Calgary, Canada
Reconciling overfishing and climate change with stock dynamics of Atlantic cod (Gadus morhua) over 500 years	Rose, GA	Canadian Journal of Fisheries and Aquatic Sciences	2004	120	6.67	2.849	University of British Columbia - Vancouver
On implementing maximum economic yield in commercial fisheries	Dichmont, CM; Pascoe, S; Kompas, T; Punt, AE; Deng, R	Proceedings of the National Academy of Sciences of the United States of America	2010	107	8.92	9.412	CSIRO, Australia
Non-linear state space modelling of fisheries biomass dynamics by using Metropolis-Hastings within-Gibbs sampling	Millar, RB; Meyer, R	Journal of the Royal Statistical Society Series C (Applied Statistics)	2000	98	4.45	1.590	University of Auckland, New Zealand

Table 2. Top 10 journals publishing on bioeconomic modeling in fisheries

Journal name	Publications	Impact factor
Fisheries Research	88	2.147
ICES Journal of Marine Science	51	3.188
Ecological Economics	36	4.482
Journal of Fish Biology	34	1.495
Canadian Journal of Fisheries and Aquatic Sciences	32	2.849
Natural Resource Modeling	31	0.915
Ecological Modeling	26	2.497
Marine Resource Economics	26	2.868
Journal of Shellfish Research	21	0.933
Aquaculture	16	3.224

Top 10 authors in bioeconomic modeling in fisheries at international level

The top three authors publishing on bioeconomic models in fisheries are Francesc Maynou (21), Patrick Lehodey (20), and Christopher Costello (18). These authors were renowned for their work on stock assessment, quantitative analysis of marine fisheries, and bioeconomic modeling in fisheries. Among the top 10 list of authors, three authors were from France. (Table 3)

Top authors in bioeconomic modeling in fisheries at national level

The top Indian authors publishing on bioeconomic modeling in fisheries were also identified for analyzing our country's research interest and gap in Indian context. Tapan Kumar Kar have 9 publications on bioeconomic modeling followed by the authors Kunal Chakraborty, Debkumar Pal having 5 publications. (Table 4)

Application of bioeconomic models in different areas of fisheries

Fisheries bioeconomics is a field that integrates resource biology and ecology with the economics of fisher behavior, considering space, time, and uncertainty dimensions (Hannesson, 1993; Seijo *et al,* 1998). Current fisheries advice requires an increased consideration of bioeconomics for evaluating the management plans (Scott *et al,* 2016). In this study, 1100 scientific publications were analyzed to identify the basic bioeconomic models applied in different areas of fisheries.

Marine fisheries

The research Interest on renewable resource economics has increased dramatically in recent years (Jerry and Raissi, 2002). Marine fisheries management is a complex process of balancing the interests of commercial fishing, recreational fishing, and the conservation of fishes (McMullin and Pert, 2010). To manage the marine fisheries resources, managers and policy-makers need information on the status of individual fish stocks for the implementation of rebuilding plans for overfished species and to increase the fish production where possible (Rosenberg *et al,* 2014). To meet these goals, we need to know about the stock status, growth parameters of the population and also to make sure that whether the fish populations are harvested at or under the maximum sustainable yield level. The basic bioeconomic models applied in marine fisheries were categorized into three and listed - Exploitation & stock status, optimal & harvesting strategies, and growth parameters (Table 5).

Marine ecosystem

Marine ecosystems make up the most extensive aquatic system in the world, covering more than 70 percent of the planet. Marine ecosystems and the services provided by the resources are beneficial to society's survival and well-being. The study on marine populations and ecosystem dynamics aims at understanding the mechanisms that govern the interactions between individuals, species, and populations, thereby enabling us to determine how the ecosystem responds to perturbations such as fishing and climate change (Anonymous, 2020c.). Under this

Table 3. Top 10 authors in bioeconomic modeling in fisheries at international level

Authors	No. of articles	Country	Affiliations
Francesc Maynou	21	Spain	Spanish National Research Council
Patrick Lehodey	20	France	CLS, Département Ecosystemes Marins
Christopher Costello	18	California, USA	University of California
Qun Liu	18	China	Ocean University of China
Inna Senina	16	France	CLS, Département Ecosystemes Marins
Andre E. Punt	16	Washington	University of Washington
Sean Pascoe	15	Australia	CSIRO Oceans and Atmosphere
Gorka Merino	14	Spain	AZTI-Tecnalia
N Chandrasekar	13	Mexico	CIBNOR-Northwest Biological Research Center, S.C.
Olivier Thebaud	12	France	IFREMER-The French Research Institute for Exploitation of the Sea

Table 4. Top authors in at bioeconomic modeling in fisheries at national level

Authors	No. of articles	Affiliations
Tapan Kumar Kar	9	Indian Institute of Engineering Science and Technology, Shibpur
Kunal Chakraborty,	5	INCOIS, Hyderabad
Dr. Debkumar Pal	5	Indian Institute of Engineering Science and Technology, Shibpur
P.U. Zacharia,	4	ICAR-CMFRI

Table 5. Bioeconomic models applied in marine fisheries

Exploitation & Stock status	Optimal Effort & Harvesting Strategies	Growth parameters
Fox surplus production model Clarke-Yoshimoto-Pooley models Pella & Tomlinson model Schaefer surplus production model Logistic surplus production model **Data poor stocks:** CMSY-Catch Maximum Sustainable Yield BSM -Bayesian Schaefer Model	Age-structured bioeconomic model Schaefer surplus production model Logistic surplus production model Fox surplus production model	Schnute model Richards model Beverton-Holt model VonBertalanffy growth model Gompertz growth model Logistic growth model **Larval Growth:** Laird-Gompertz model

category, the bioeconomic models were classified into seven groups (Table 6).

Mixed fisheries management is a complex process, and the stocks sustainable level cannot be predicted by using a single species bioeconomic model, which requires a separate bioeconomic model for addressing the stock status, optimal harvesting, and exploitation status. Prey-Predator models are used to know about the species interaction for resource conservation and to explain the dynamics of the biological system. The prey-predator models are adjusted based on the number of preys and predators. Oyster and seaweed grounds are analyzed for the economic benefits/feasibility of the cultivation of oysters, seaweeds, and scallop. The bioeconomic model for analyzing economic feasibility consists of biological, technological, and economic sub-

Table 6. Bioeconomic models applied in marine ecosystems

Aspects	Bioeconomic models
Mixed fisheries	Spatially explicit bioeconomic model- ISIS-Fish Tool SOMER model Multispecies, Multifleet model
Prey-Predator model	Lotka-Volterra model Leslie-Gower prey-predator bioeconomic model Gause-type predator-prey model Beddington-DeAngelis type predator-prey model
Oyster, Seaweed grounds	STELLA software- Dynamic simulation model
Ecosystem valuation	InVEST model-Integrated Valuation of Ecosystem Services and Trade-offs Dynamic bioeconomic model Ecosim model
Exploitation levels and fish abundance	Multi-Annual Generalized Depletion (MAGD) model Surplus production model in continuous time (SPiCT) Bayesian state-space surplus-production model
Interactions between the fleet	Multi-species, multi-gear bioeconomic game-theoretic bioeconomic model
By catch	Multispecies, multifishery bioeconomic model Single cohort model

models. Ecosystem valuation is a process of assigning values to an ecosystem or ecosystem services. It is important for ecosystem conservation and to know about the benefits provided by the ecosystem. Other than that, the bioeconomic models are also identified and listed based on their utilization into - Exploitation levels and fish abundance for fisheries with limited information, Effect of climatic changes on surplus production, Interactions between the fleet, and Bycatch.

Marine reserve/marine protected area

Marine protected areas (MPAs) play an important role in the protection and conservation of ocean ecosystems. MPAs can be conserved for several reasons, including economic resources, biodiversity conservation, and species protection. Marine reserve is also a type of marine protected area that has legal protection against fishing or development. Marine Protected Area can be used for specific fishery management ends such as restricting the fishing fleet's impact on fish stock, or protecting an ocean area (Sumaila, 2002). Bioeconomic models are important in predicting the consequences of management decisions and the design of monitoring programs in terms of policy goals (Beattie *et al,* 2002), and few have been listed in Table 7.

Table 7. Bioeconomic models applied in MPA/marine reserve

Marine Reserve	Marine Protected Area
Reserve based management (effects/economic performance): Spatial Bioeconomic model Bioeconomic model of optimal marine reserve switching Bioeconomic model of spatial exploitation. Atlantis end-to-end model **Economic profits:** Spatial Bioeconomic model with integrodifference model	Multispecies, multiarea stock assessment-Spatially explicit surplus production model BEMCOM -BioEconomic Model to evaluate the Consequences of Marine protected areas **Ecological benefits:** Spatially explicit bioeconomic optimal control model of two patches

Aquaculture

Bioeconomic modeling is not only essential for modeling marine stocks/resources but also for inland water bodies for their efficient management and utilization, for sustainably increasing the resource use efficiency. Bioeconomic models are a good methodological approach to study the interaction of the various components (biological, physical, technological, economic, institutional) of aquaculture systems (Pomeroy *et al,* 2008). Bioeconomic models can provide answers to the questions of economic feasibility, optimal system design, optimal methods of operations, and research direction (Leung, 1994). Based on literature few most common bioeconomic models used in aquaculture are listed in Table 8

Recreational fisheries

In many countries, recreational fisheries are an established activity. There is a lack of knowledge on the basic biology of threatened species and the management of the recreational fishery. For conservation and management of the recreational fishery, the behavior and preferences of an angler is considered in building the bioeconomic model. Few models used in recreational fisheries are listed in Table 9.

Simulation software's/tools

Bioeconomic simulation techniques have recently been developed to simulate the whole process of stock dynamics, fishing activity, fishery assessment, and management as an adaptive process (Grant *et al,* 1981). The simulation software/tools and its application are listed in Tables 10 and 11.

Simulation tools in a specific region

The objective of the simulation model in a specific region is to reproduce the bioeconomic conditions in which the fisheries occur. The study identified some of the tools used in specific regions from the 1100 collected publications and listed them in Table 12.

Most published thematic areas within bioeconomic modeling in fisheries

The major thematic areas within bioeconomic modeling in fisheries were identified using an online content analysis tool Word It out. The analysis was done by taking all the titles of 1100 publications as input for the identification of the thematic areas. The results showed that "growth", "model", "management", "bioeconomic", "fisheries" and "fishery" are the most published thematic areas (Figure 5)

Conclusion and Policy Implications

This research work provides the quantitative assessment of scientific literature on the use of bioeconomic models in fisheries. The findings of this study will help a researcher working on modeling and, to know about the bioeconomic models and

Table 8. Bioeconomic models applied in aquaculture

Bioeconomic model developed by Besson et al., 2014 -Fish+ Farm+ Batch sub models
Bioeconomic optimization model- biological+ environmental+ management+ economic sub models
Bioeconomic simulation model-population dynamics+ harvest strategies
Horizontally integrated temperate and warm water land-based marine aquaculture systems:
GENESIS bioeconomic model
Impacts of invasive fish- Lotka –Volterra interspecific competition model

Table 9. Bioeconomic models applied in recreational fisheries

Application	Bioeconomic model
Angler behaviour& Optimal management	1.Integrated model-Angler type specific utility+ Age structured population model 2.Bioeconomic landscape simulation model
Interactions between Recreational and commercial fisheries	Bioeconomic model of recreational and commercial fisheries
Overexploitation	Multistate capture-recapture model

Table 10. Simulation software's/tools

Software/Tools	Uses	Type
CEDA-catch-effort data analysis	Catch, effort and abundance index data	Free software
ASPIC- A Stock-Production Model Incorporating Covariates	Catch, effort and abundance index data	Free software
SEMIPRO-Spatial surplus production model	Distribution and movement of fish populations	Programmed in AD Model Builder software
Enhance Fish model	Quantitative assessment of aquaculture-based fisheries enhancements	Free software
JABBA-Just Another Bayesian Biomass Assessment-biomass dynamic stock assessment application	Dynamic stock assessment	R Package
DISPLACE model- Vessel-oriented decision-support tool	Spatial planning, marine management	Free software
BEMTOOL	Management of multi-stock & multiple gears fisheries	Bemtool v.2.5-R package
FLR-Fisheries Laboratory in R	Series of packages for quantitative fisheries science	R package
FiSAT- FAO-ICLARM stock assessment tool	Stock assessment and fisheries management	Free software
BOATS- Bioeconomic marine Trophic Size-spectrum model	Model fish biomass at the global scale	Code is written in MATLAB version R 2012
Ecopath with Ecosim model	Ecological/ecosystem modeling	Free modeling software suite
BEAM4 Bio Economic Analytical Model	Management of exploited living aquatic resources	Free software
SEAPODYM- Spatial Ecosystem and Population Dynamics Model	Tuna management	ADModel Builder-Autodif libraries libado and libadt
SEAPODYM-MTL	Micronekton biomass	ADModel Builder-Autodif libraries libado and libadt

Table 11. Software and its applications in bioeconomic modeling

Software/Tool	Uses
EconSimp2000	Economic impacts of global warming
SPATIAL- Space time Dynamics in Marine Fisheries	Software package for sedentary species
FISH-BE-Fisheries Information for Sustainable Harvests-Bio Economic model	MPA effects on fishing
FishRent-bio-economic simulation and optimization model	Evaluation of Fishery management
CLIMPROD	To fit surplus production models
APECOSM-E model	Population dynamics of tropical tuna
Fcube and FcubEcon models	Effort allocation and management
Fcube-Fishery and Fleet Forecasts	Total Allowable Catch for mixed fisheries
FLEBIA	Evaluation of fisheries management strategies

Table 12. Simulation tools in specific region

GAMEFISTO model-GAMEs in Mediterranean FIsheries Simulation Tools
MEFISTO-Multispecies, multifleet and multigear simulation model
SRRMCF-Swedish Resource Rent Model for the Commercial Fisheries
ERSEM-The European Regional Seas Ecosystem Model
BECHAMEL-BioEconomic CHAnnel ModEL-bioeconomic simulation model of the English Channel fisheries

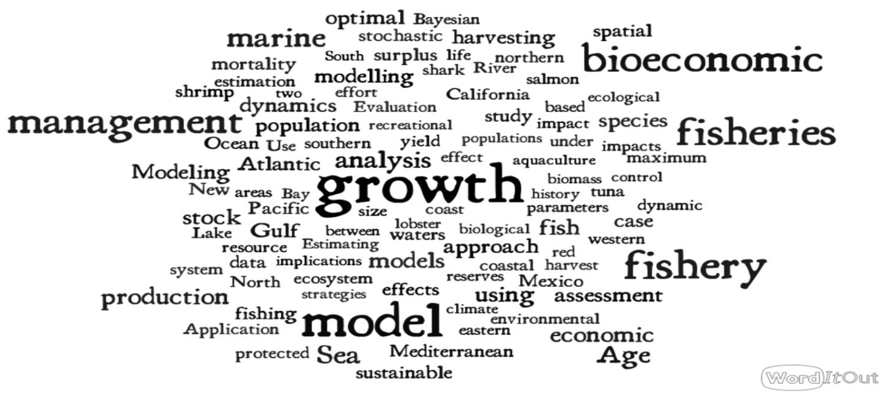

Figure 5. Most Published Thematic Areas within "Bioeconomic Modeling in Fisheries"

their applications in the respective fields. The study is envisaged to highlight the importance and need of bioeconomic modeling in the near future for optimal fisheries management and generating evidence-based policy framework.

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References

Anonymous 2020a. *The State of World Fisheries and Aquaculture*. Fisheries and Aquaculture Department, Food and Agriculture Organization. https://www.fao.org/publications/sofia/2020/en/

Anonymous 2020c. *Research into Marine Populations and Ecosystems Dynamics*. National Institute of Aquatic Resources. https://www.aqua.dtu.dk/english/research/marine-ecosystems

Anonymous 2021b. *Oceans, Fisheries and Coastal Economies*. The World Bank. https://www.worldbank.org/en/topic/oceans-fisheries-and-coastal-economies

Allen P G, Botsford L W, Schuur A M and Johnston W E 1984. *Bioeconomics of Aquaculture*. Elsevier.

Anderson L G and Seijo J C 2010. *Bioeconomics of Fisheries Management*. John Wiley & Sons. https://agris.fao.org/agris-search/search.do?recordID=XF2016053771

Beattie A, Sumaila U R, Christensen V, Pauly D 2002. A Model for the bioeconomic evaluation of marine protected area size and placement in the North sea. *Natural Resource Modeling* **15**:413–437. http://legacy.seaaroundus.s3.amazonaws.com/doc/Researcher+Publications/dpauly/PDF/2002/JournalArticles/ModelBioeconimicEvaluationMPANorthSea.pdf

Clark C W 2006. Fisheries bioeconomics: why is it so widely misunderstood? *Population Ecology* 48:95-98. https://doi.org/10.1007/s10144-006-0255-2

Cochrane K L and Garcia S M 2009. *A Fishery Manager's Guidebook*. John Wiley & Sons. https://www.ipcc.ch/apps/njlite/ar5wg2/njlite_download2.php?id=10686

Conrad J M and Smith M D 2012. Nonspatial and spatial models in bioeconomics. *Natural Resource Modeling* **25**:52-92. https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1939-7445.2011.00102.x

Grant W E Isakson K G Griffin W L 1981. A general bioeconomic simulation model for annual-crop marine fisheries. *Ecological Modelling* **13**:195–219. DOI: 10.1051/alr:2007035

Habib A Ullah M and Duy N N 2014. Bioeconomics of commercial marine fisheries of Bay of Bengal: Status and direction. *Economics Research International* **2014**: 1-10. https://doi.org/10.1155/2014/538074

Hannesson R 1993. *Bioeconomic Analysis of Fisheries*. Fishing News Books Ltd. https://books.google.co.in/books/about/Bioeconomic_Analysis_of_Fisheries.html?id=XYoRAAAAYAAJ&redir_esc=y

Jerry M and Raïssi N 2002. The optimal strategy for a bioeconomical model of a harvesting renewable resource problem. *Mathematical and Computer Modelling* **36**:1293–1306. DOI: 10.1016/S0895-7177(02)00277-7

Kar T K and Matsuda H 2006. An overview of bioeconomic analysis and management in fisheries. *Journal of Fisheries and Aquatic Science* **1**:218-234. DOI: 10.3923/jfas.2006.218.234

Leung P S 1994. Bioeconomic modeling in aquaculture after two decades. In: *Socioeconomics of Aquaculture*, TungKang Marine Laboratory, Conference Proceedings, Taiwan, 115–137,1994. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1021.9958&rep=rep1&type=pdf

McMullin S L and Pert E 2010. *The Process of Fisheries Management. Inland fisheries management in North America*. American Fisheries Society. https://www.webpages.uidaho.edu/fish510/PDF/McMullin%20&%20Pert%20IFM.pdf

Pauly D, Christensen V and Walters C 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science* **57**:697-706. https://doi.org/10.1006/jmsc.2000.0726

Pomeroy R, Bravo Ureta B E, Solis D and Johnston R J 2008. Bioeconomic modelling and salmon aquaculture: an overview of the literature. *International Journal of Environment and Pollution* **33**:485-500. DOI: 10.1504/IJEP.2008.020574

Rosenberg A A Fogarty M J Cooper A B Dickey-Collas M Fulton E A Gutiérrez N L Hyde K J Kleisner K M Kristiansen T Longo C and Minte-Vera C V 2014. Developing new approaches to global stock status assessment and fishery production potential of the seas. *FAO Fisheries and Aquaculture Circular* 1086:75. https://www.fao.org/3/i3491e/i3491e00.htm

Sanchirico J N and Wilen J E 2001. A bioeconomic model of marine reserve creation. *Journal of Environmental Economics and Management* **42**:257-276. DOI:10.1006jeem.2000.1162

Scott F and Sanchez IM 2016. *Bioeconomic Modelling for Fisheries*. EUR 28383 EN. Luxembourg Publications Office of the European Union. DOI: 10.2788/722156

Seijo J C, Defeo O and Salas S 1998. *Fisheries Bioeconomics: Theory, Modelling and Management* (No. 368). Food & Agriculture Organization. https://www.fao.org/3/W6914E/W6914E00.htm

Sumaila U R and Charles A T 2002. Economic models of marine protected areas: an introduction. *Natural Resource Modeling* **15**:261-272. DOI: 10.1111/j.1939-7445.2002.tb00089.x

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