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Trends, Opportunities, and Networking in Marine Biotechnology

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Project: 101129136 — SustainaBlue — ERASMUS-EDU-2023-CBHE

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Content

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Trends in Marine Biotechnology

Between 2010 and 2020, 620 publications relating to marine biotechnology with applications in the food and pharmaceutical industries were created.

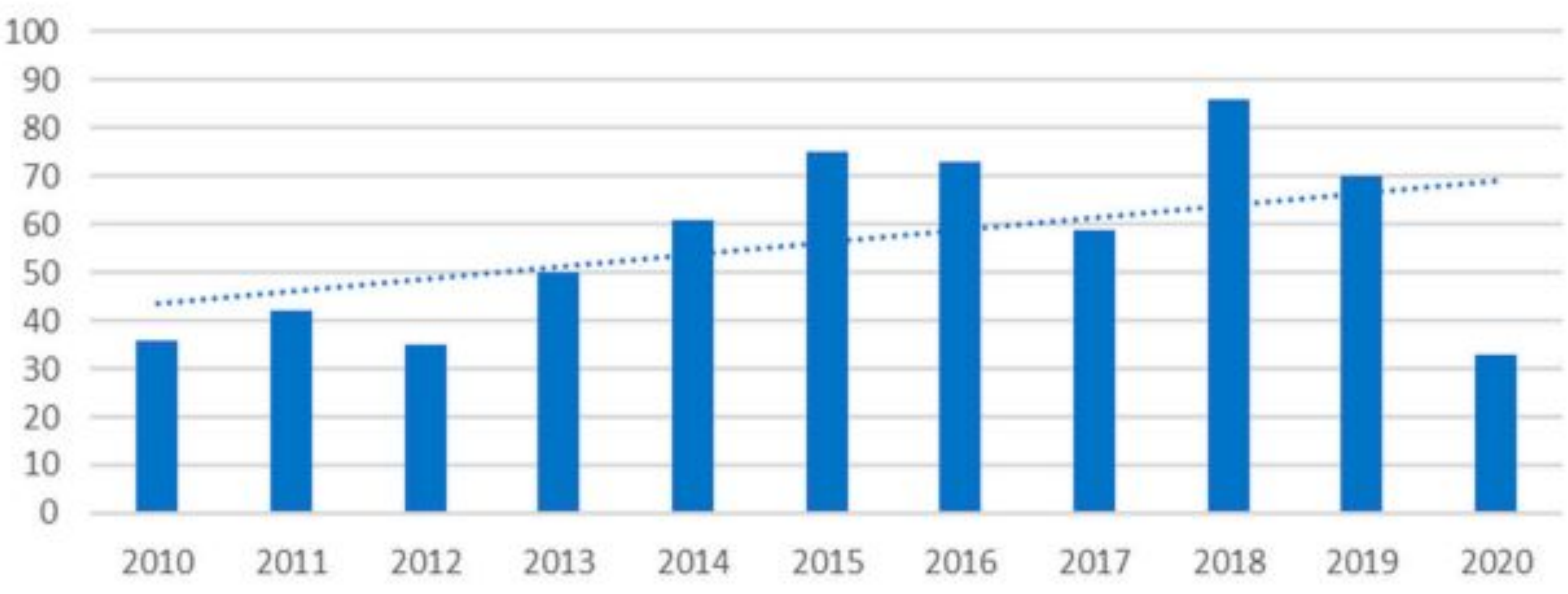

Figure 1. Worldwide scientific production from 2010 to 2020.

marine biotechnology in the context of pharmaceuticals and food is most widely studied is Asia, with 312 publications (50%), followed by Europe with 208 (33.5%), as can be seen in the graph in Figure below.

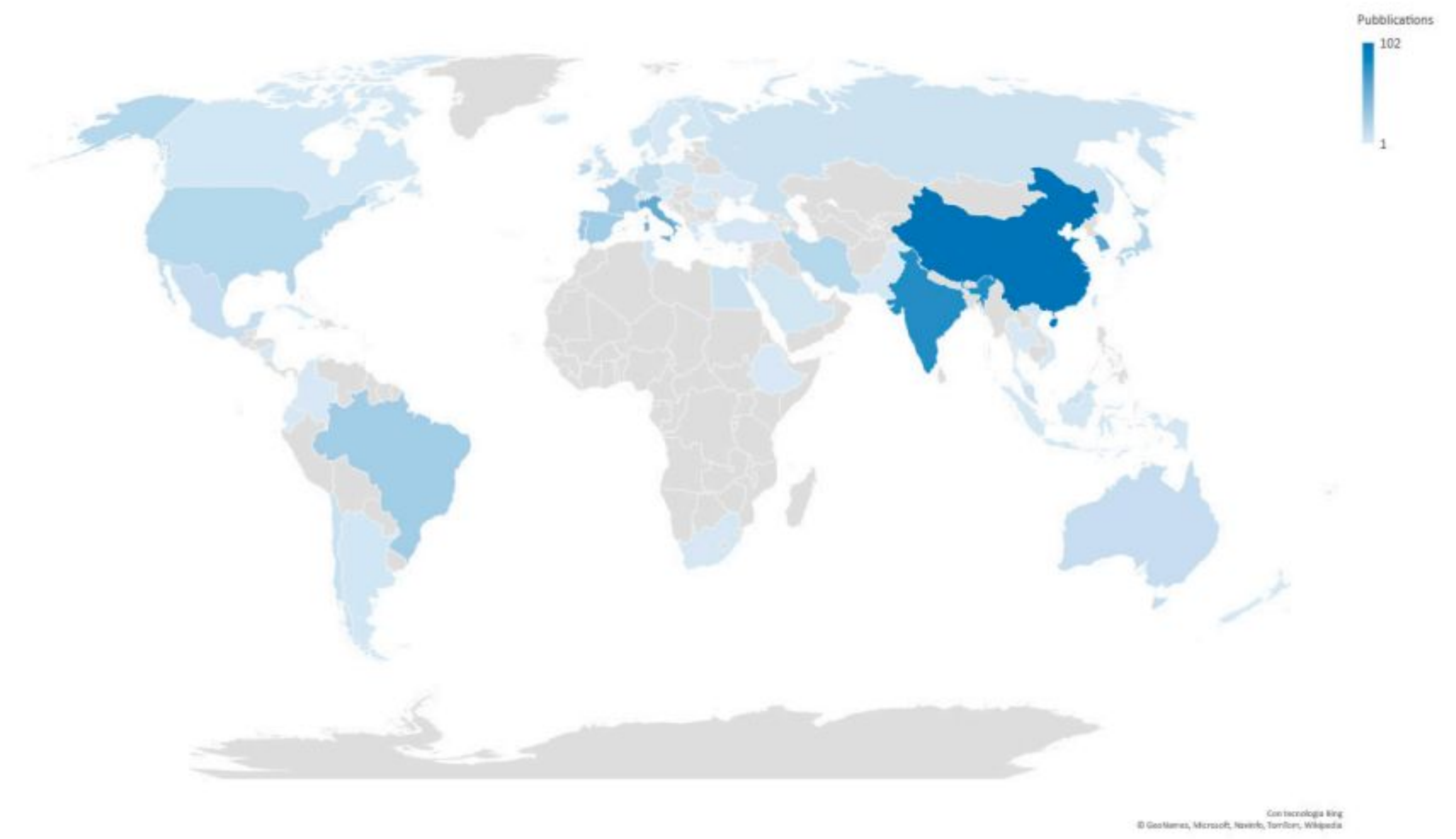

Figure 2. Geographical distribution of publications in the world.

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Trends in Marine Biotechnology

Marine biotechnology, also known as **blue biotechnology**, is currently experiencing a **booming trend in development and utilization**. Despite being considered "in its infancy" compared to its vast potential, with over 70% of the Earth's surface covered by oceans and an estimated 25% of the world's species residing there, the market is projected for significant expansion. The global marine biotechnology market is expected to reach approximately **$6.4 billion by 2025**. This growth is largely driven by the **enormous diversity of marine biota** remaining largely unexplored and unexploited.

- **Accelerated Product Discovery and Market Expansion**:
  - There has been a significant rise in the discovery of new marine natural products, with over **1,000 new products discovered annually since 2008**. This is attributed to advancements in analytical methods like **mass spectrometry (MS) and high-resolution Nuclear Magnetic Resonance (NMR) spectrometers**.

A total of 79 keywords with a frequency of 30 or more occurrences were identified, and Table 1 shows the top 20 keywords according to frequency. Keywords such as microalgae, seaweed, marine plants, marine animals, and marine microbes were located at the top of the frequency of occurrence, indicating that they are the primary keywords in marine bioindustry research.

Table 1. *Keyword frequency.*

Ranking	Keywords	Frequency
1	Microalgae	224
2	Seaweed	140
3	Marine Plant	124
4	Marine Animal	121
5	Marine Microbe	117
6	Reference Genome	117
7	Functional Gene	114
8	Monitoring	112
9	Marine Biomaterials	93
10	Marine Microalgae	88
11	Marine Biotechnology	83
12	Biomarker	81
13	Health Functional Food	78
14	Biosensor	77
15	Climate Change	76
16	Functional Food	74
17	Biomass	73
18	Chemical Industry Materials	68
19	Marine Bioplastics	68
20	Marine Fiber and Complex Materials	68

(Source: Jang-Hyung Han et. al, 2023)

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Trends: Marine Compound

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Distribution of marine organisms used in pharmaceutical and food applications of marine biotechnology, by publication.

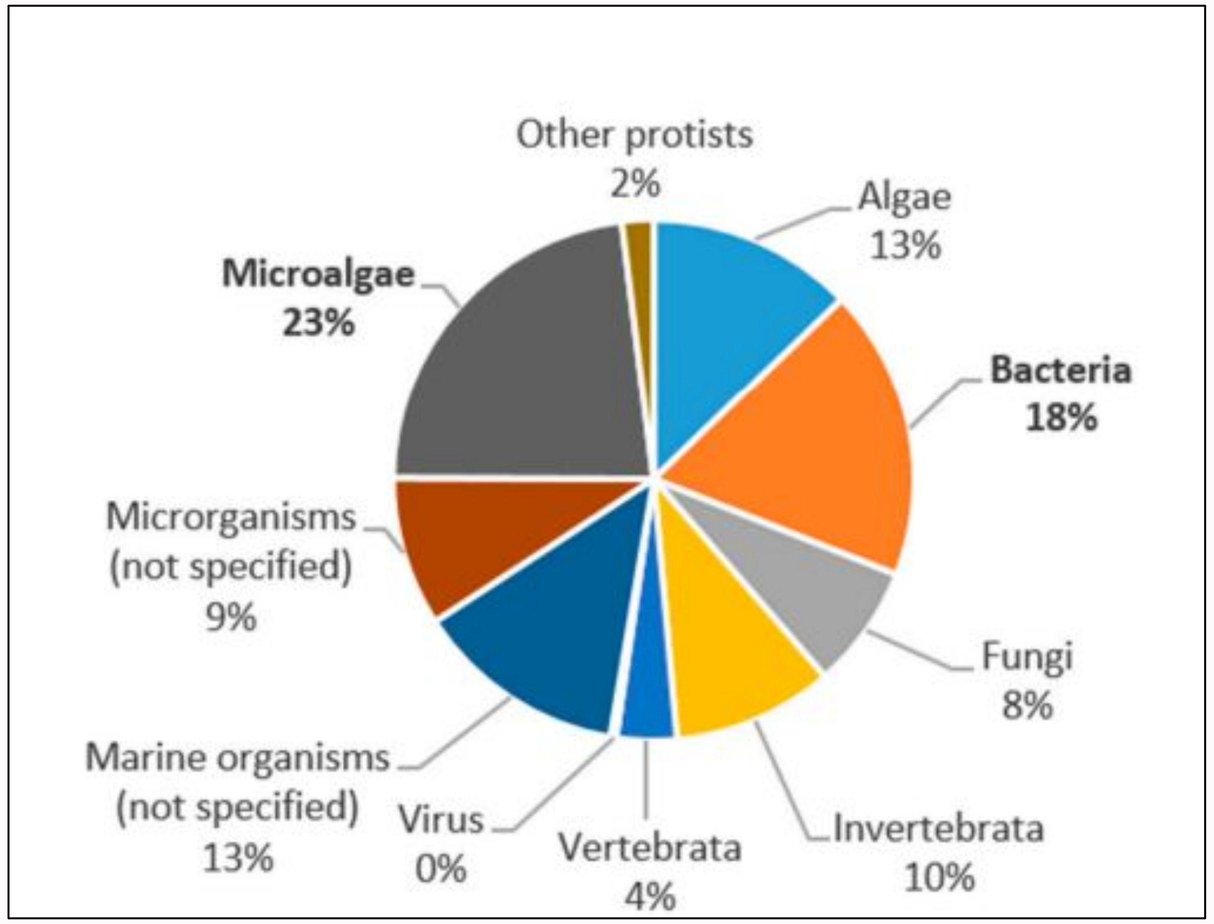

Table 1

Production and detailed information about key marine-derived molecules reported from 2018–2020

Compound	Source	Host strain	Content or titer	Reference
Astaxanthin (**1**)	Shrimp wastes; *Haematococcus pluvialis*; *Xanthophyllomyces dendrorhous*	*Escherichia coli*	7.12 mg/g DCW (432.82 mg/L) (bioreactor)	[52]
		E. coli	11.92 mg/g DCW (shake-flasks)	[53]
		E. coli	15.1 mg/g DCW (shake-flasks) 320 mg/L (bioreactor)	[54••]
		Saccharomyces cerevisiae	13.8 mg/g DCW (217.9 mg/L) (bioreactor)	[55]
		S. cerevisiae	235 mg/L (bioreactor)	[56]
		Yarrowia lipolytica	6 mg/g DCW (285 ± 19 mg/L) (bioreactor)	[57••]
		Haematococcus pluvialis	45.8 mg/Kg of raw biomass	[58]
Zeaxanthin (**2**)	Cyanobacteria; Microalgae; Higher plants	*Chlorella zofingiensis CZ-bkt1*	36.79 ± 2.23 mg/L (bioreactor)	[59]
		Sphingobium DIZ	479.5 mg/L (bioreactor)	[60]
Fucoxanthin (**3**)	Diatoms; Seaweeds	*Cylindrotheca closterium*	25.5 mg/g DCW (bioreactor)	[61]
Squalene (**4**)	Shark liver oils	*S. cerevisiae* Y2805	2011 ± 75 mg/L (bioreactor)	[62]
		E. coli	28.5 mg/g DCW (52.1 mg/L) (bioreactor)	[63]
Shinorine (**5**)	Cyanobacteria; Macroalgae	*Synechocystis* sp. PCC6803	2.37 ± 0.21 mg/g DCW (shake-flasks)	[64]

(Source: Daniotti & Ilaria, 2021)

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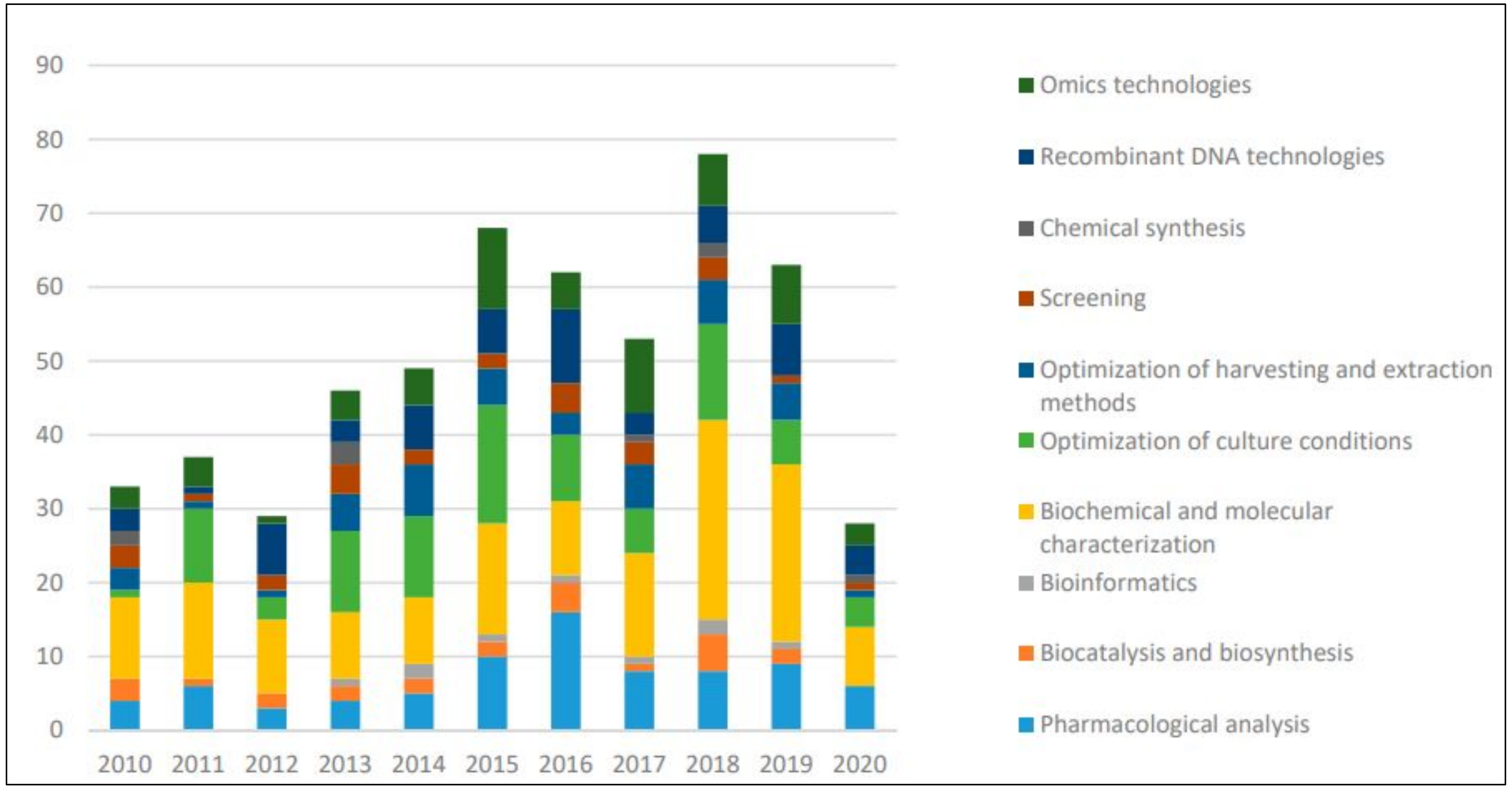
Trends: Technology in Marine Biotechnology



(Source: Daniotti & Ilaria, 2021)

The analysis of articles from 2010 to 2020 reveals distinct trends in the application of these technologies:

- **"Biochemical and molecular characterization"** was the most widely used technology, applied in **150 studies (24% of the total)**, showing consistent annual growth and peaking in 2018. However, as a basic technology, it does not provide the necessary added value to innovate the drug discovery process and is not considered among the emerging trends for future research.
- Following in terms of publication numbers were **"optimization of growing conditions" (15%)** and **"pharmacological analysis" (13%)**.
- **"Omics technologies" (10%)** also showed a steady growth trend over the decade.
- **Growth Trends Comparing 2015-2019 to 2010-2014:** When comparing the number of publications in the last five years (2015–2019) to the preceding period (2010–2014), almost all categories showed a positive increase, with a few exceptions:
- **"Chemical synthesis"** was the only category to show a **decrease of 40%**.
- Categories with **less than 50% increase** included:
  - "Screening" (+8.3%).
  - "Optimization of culture conditions" (+38.9%).
  - "Biocatalysis" (+40%).
  - "Optimization of harvesting and extraction methods" (+47%).
- Technologies that **more than doubled** their publication numbers in the latter five-year period (2015–2019) compared to 2010–2014, making them key emerging trends, include:
  - **Bioinformatics (+100%)**.
  - **Pharmacological analysis technologies (+131.8%)**.
  - **Omics technologies (+141%)**.
- A substantial increase was also observed for **"recombinant DNA technologies" (+55%)**.
- These emerging technologies (omics, pharmacological analysis, and bioinformatics) are primarily utilized for the **discovery of new organisms or products of marine origin**, aligning with the objectives of basic research often conducted by universities and research centers.

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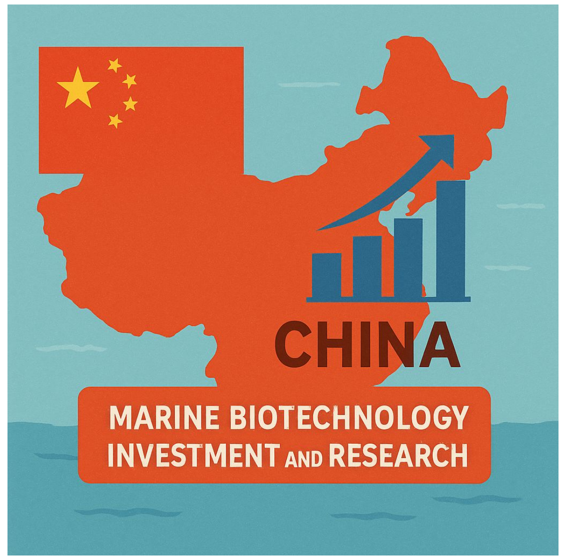
Geographical Trends in China

Marine biotechnology has become a key field for national economic development in China, particularly since the 12th Five-Year Plan. The nation has recognized the importance of marine biotechnology to address its large population and the constant increase in grain prices. China has significantly enhanced the development of high technologies and improved the benefits of the marine industry. Its level of technical research and development investment is considered advanced, comparable to powerful nations like the USA and Japan.



Key aspects of China's involvement in marine biotechnology include:

- **Policy and Investment:** The Chinese government has encouraged the marine sector as a strategic pillar for economic growth since 1996 through subsidies and tax incentives. Marine biotechnology is seen as the main tool to "exploit the sea using science and technology," a strategic goal of the government. Following the 12th Five-Year Plan, the State Oceanic Administration, in conjunction with the State Council, issued new specifications such as the Bioindustry Development Planning and National Marine Affairs Development Planning, emphasizing the importance of marine biotechnology.
- **Market Share and Products**: In 2015, the global marine biotechnology industry's total output value reached $78 billion US dollars, with China contributing $20 billion US dollars. Functional food and pharmaceutical industries involving marine life are advancing steadily, and many marine drugs and health care products have been approved for sale. Examples include "artificial skin" technology for tissue repair, which has reached international advanced levels, and new anti-cancer, anti-tumor, and anti-AIDS drugs derived from marine biotechnology, which have driven the national economy.
- **Scientific Research Leadership:** China leads globally in scientific publications in marine biotechnology applications for pharmaceuticals and food, with 102 publications. It also boasts the highest average impact factor in Asia (4.174).
- **Leading Research Centers:** Four of the top ten global research centers in this field are in China. The Ocean University of China is the top institution globally with 18 publications, specializing in biochemical and molecular characterization (39%) and recombinant techniques (22.2%). The Chinese Academy of Sciences also stands out for its recombinant (33%) and screening (27%) techniques, and has collaborated on European projects like PharmaSea and MGATech.
- **Technological Focus:** Chinese research predominantly utilizes biochemical and molecular characterization techniques, optimization of culture conditions (22.5% of Chinese publications), and recombinant techniques (13%).

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Geographical Trends in Europe

The market in Europe is projected to reach $1301.85 million, with pharmaceuticals and food accounting for over 60% of the added value.

Policy and Funding:

- The Blue Growth Strategy, adopted in 2012 by the European Commission, is a primary contribution to identifying long-term, sustainable growth strategies, with marine biotechnology as a key component.
- The Horizon 2020 program (2014–2020), Europe's largest research and innovation program with an €80 billion allocation, features a dedicated "Blue Growth" investment line. It utilizes instruments like the SME Instrument (now EIC Accelerator Pilot), which funds high-TRL projects for commercialization, and the Bio-based Industries Joint Undertaking (BBI-JU), a public-private partnership for biorefineries.
- From 2014 to 2020, the European Commission allocated over €149 million to 29 projects in the Blue Growth sector focused on food and pharma applications. The funding distribution varied by project type: €98.48 million for BG projects, €43.87 million for BBI projects, and €7.08 million for SME instrument projects, with SME instrument projects typically having higher TRL (Technology Readiness Level) values (TRL 8 or more).

Scientific Research and Leading Countries: Europe accounts for 33.5% of global scientific publications in marine biotechnology for pharmaceutical and food applications.

- Italy is the leading country in Europe for scientific research, ranking fourth globally with 55 publications, representing over a quarter of Europe's total studies. Italian research quality, measured by average impact factor, ranks third in Europe behind Portugal and Spain.
- Italian centers of excellence include the Anton Dohrn Zoological Station, which is first in Europe and second globally in publications and specializes in omics technologies (30%), and the National Research Council of Naples, which focuses on biosynthesis and biocatalysis (20%).

- **Technological Focus and Business Models**: High-TRL projects in Europe predominantly focus on optimizing cultivation conditions and harvesting/extraction methods (used in over 65% of high-maturity projects), often combined with recombinant technologies, to address sustainability and productivity challenges.

Non-Indigenous Species (NIS) Management: European Union policies, like the Marine Strategy Framework Directive (MSFD), address marine NIS. The overall number of new introductions has steadily increased since 2000, reaching an annual rate of 21 new NIS in European seas during 2012–2017. The Baltic Marine Environment Protection Commission (HELCOM) has set a numerical threshold of zero new NIS introductions through anthropogenic activities in the Baltic Sea. Despite this, new NIS records persist, suggesting ongoing challenges. The increase in NIS is likely due to increased human activities and research efforts.

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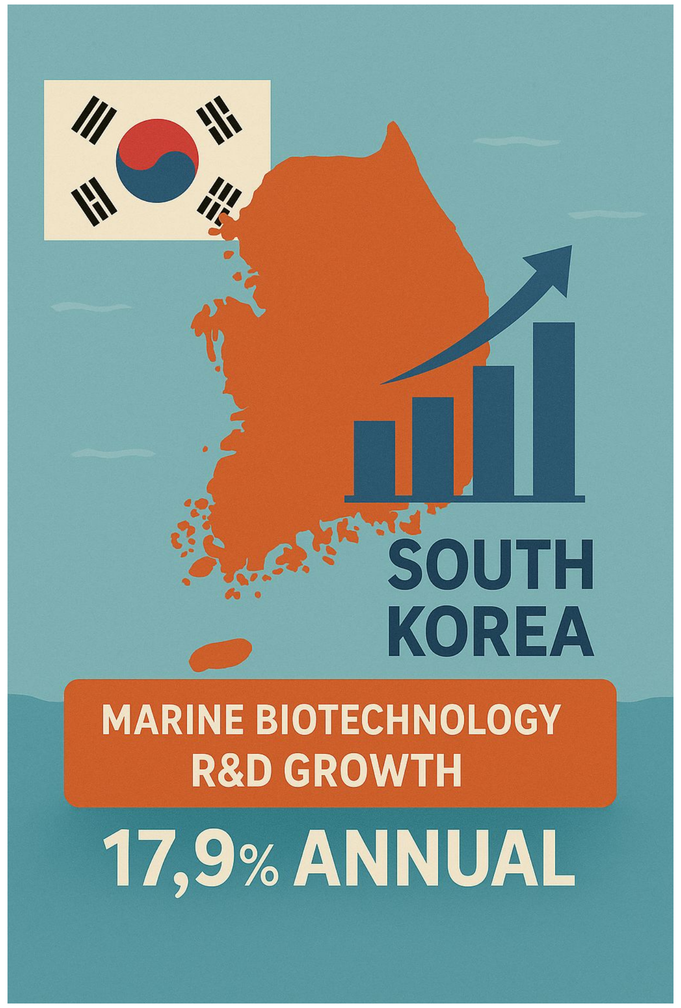
Geographical Trends in South Korea



South Korea actively invests in marine biotechnology research and industrial development, recognizing its importance.

Key aspects of South Korea's involvement include:

R&D Growth and Investment: R&D projects related to marine bio-industry in Korea have shown a high annual average growth rate of 17.9% from 2002 to 2022, increasing from 20 projects in 2002 to 542 in 2022. The Ministry of Oceans and Fisheries invested KRW 248.6 billion in national R&D projects in the marine biosector from 2005 to 2017. While investment increased significantly (e.g., 4.5 times from 2005 to 2017), it remains at a lower level compared to other ministries, and commercialization performance is "relatively weak".

Key Research Topics:

- In the early 2000s, research focused on biotechnology, bioindustry, functional food, marine bioindustry, biosensors, and probiotics.
- As of 2022, central research topics include blue carbon, climate change, carbon storage, living shoreline, tidal flats, and functional foods.
- Consistently appearing as major keywords across all sections are: microalgae, seaweed, marine plants, marine animals, marine microbes, reference genomes, functional genes, monitoring, marine biomaterials, and marine microalgae.
- Keywords like "marine," "marinebio," and "algae" show high eigenvector and betweenness centrality, indicating their central role in research.

Scientific Publications: South Korea is a significant contributor to scientific research, ranking third globally with 61 publications related to marine biotechnology in pharmaceutical and food applications.

Technological Focus: South Korean publications prominently feature pharmacological analysis (21% of their publications).

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Role of Quadruple Helix

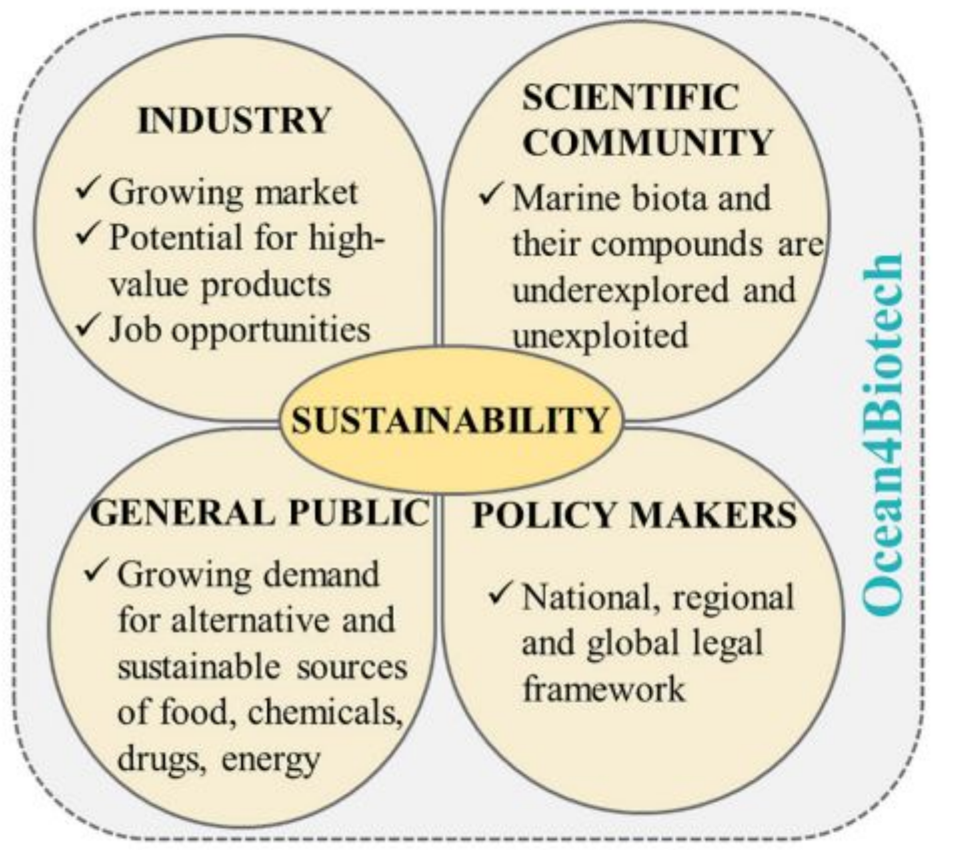

FIGURE 2 | Major prerequisites for the establishment of sustainable actions in marine biotechnology.

1. Scientific Community
Role: Drives research and innovation by exploring marine biodiversity, developing high-throughput screening methods, cultivating marine organisms, and optimizing bioactive compound extraction.
Contribution to Sustainability: Develops eco-friendly bioprospecting methods, promotes responsible innovation, and contributes to sustainable marine resource use.

2. Industry
Role: Translates research outcomes into commercial products such as biofuels, pharmaceuticals, nutraceuticals, and biomaterials.
Contribution to Sustainability: Encouraged to adopt green technologies, apply life cycle sustainability assessments, and support public-private partnerships for sustainable production and commercialization.

3. Policy Makers
Role: Provide regulatory frameworks, ensure compliance with environmental laws, and facilitate ethical bioprospecting and benefit-sharing (e.g., Nagoya Protocol, EU directives).
Contribution to Sustainability: Support legislation and international cooperation to promote marine biotechnology while protecting marine biodiversity and ecosystem services.

4. General Public
Role: Acts as consumers and beneficiaries of marine biotech products and must be informed and engaged.
Contribution to Sustainability: Increased awareness leads to greater demand for sustainable and eco-friendly products, driving responsible consumption and market support for green innovations.

These stakeholders must work together within a **transdisciplinary and transnational framework** to achieve sustainable and responsible development in marine biotechnology.

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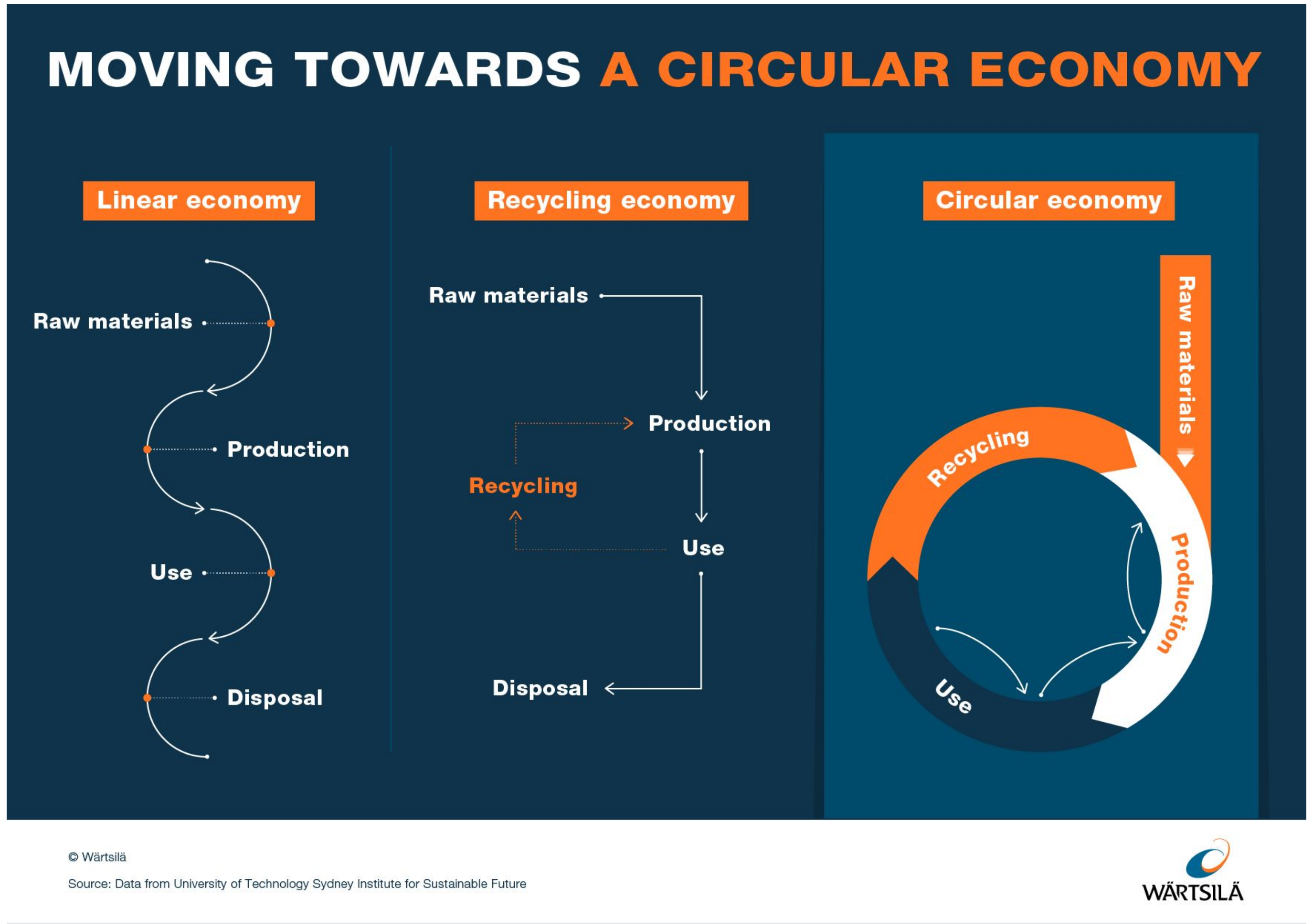
Current Marine Biotech Trend is to Emphasis on Sustainability and Circular Economy



There is a growing focus on the **sustainable exploitation of marine bio-resources**. This involves valorizing **side and waste streams** (e.g., from the fishing industry to produce high-value products like protein hydrolysates or collagen) and targeting sustainably cultured marine organisms.

Green production techniques, such as enzymatic methods for product synthesis (biocatalysis and biosynthesis) that reduce the use of toxic compounds, are also being prioritized.

Aquaculture is recognized as a critical solution to world fisheries problems and is expected to increase production seven-fold by 2025 to meet demand. It also represents an alternative to unsustainable exploitation of wild marine fauna.

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Collaborative Networks and Responsible Research and Innovation (RRI):

There is a recognized need for **effective, transnational, and transdisciplinary networks** connecting industry, researchers, the public, and policymakers to foster marine biotechnology and bioeconomy sustainably.

- Initiatives like **Ocean4Biotech**, a COST Action, aim to connect stakeholders, share infrastructure, facilitate knowledge exchange, and promote career advancement.
- Marine biotechnology development is increasingly guided by **RRI principles**, which include ethics, open access, gender equality, governance (adhering to international conventions like the Convention on Biological Diversity and the Nagoya Protocol), public engagement, and science education.

Ocean4Biotech COST Action CA18238

https://www.ocean4biotech.eu/

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Marine Biotech Contributes to Global Contribution to Economic Growth

- In 2015, the total output value of the global marine biotechnology industry reached $78 billion US dollars, with China contributing a substantial $20 billion US dollars. The global marine biotechnology market is expected to reach approximately $6.4 billion by 2025, with functional food and pharmaceutical industries involving marine life advancing steadily.
- The industry generates various products, ranging from high-volume, low-value products like biofuels and feedstuffs to high-value, high-risk products such as new biomaterials, cosmetics, nutraceuticals, and pharmaceuticals.
- Marine organisms produce a vast diversity of metabolites useful for humans, including cytotoxic, antioxidant, antimicrobial, anticancer, and nutritional compounds. These metabolites help satisfy the increasing demand for alternative sources of nutraceuticals, pharmaceuticals, cosmeceuticals, food, feed, and novel bio-based products.
- For example, functional food and pharmaceutical industries are advancing steadily, and many marine drugs and health care products have been approved for sale. Successful commercialized products include the analgesic Prialt®, the antihypertensive Lovaza®, and anticancer agents like Yondelis® and Cytosar-U®.
- The European market for marine biotechnology is projected to reach $1301.85 million, with the pharmaceutical and food sectors accounting for over 60% of the added value.
- European efforts are guided by the Blue Growth Strategy, adopted in 2012 by the European Commission, which identifies marine biotechnology as a key component for long-term sustainable growth.
- The Horizon 2020 program (2014–2020) is Europe's largest research and innovation program, allocating over €149 million to 29 projects in the Blue Growth sector focused on food and pharma applications. This funding is distributed through instruments like the Blue Growth (BG) calls, Bio-based Industries Joint Undertaking (BBI-JU), and the SME Instrument (now EIC Accelerator Pilot).
- Projects with high Technology Readiness Levels (TRL 6-8), often funded by the SME Instrument, concentrate on technologies for optimizing cultivation conditions, harvesting, and extraction methods, which are crucial for commercial exploitation.
- Nutraceutical and functional food sectors are expected to lead the European market trend due to less stringent legislation and lower investment requirements compared to pharmaceuticals, while also sustainably meeting food demands.
- The European marine biotechnology market largely consists of some 140 micro SMEs and academia, which often lack the financial stability for sustained, long-term cutting-edge research, highlighting the need for public-private partnerships and networking activities.

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Marine Potential in Indonesia

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Indonesia, as the world's largest archipelagic country, possesses a vast marine and coastal area.
Specifically:

- The **marine sea area of Indonesia** is reported to be **5.8 million km2**.
- More detailed figures indicate that Indonesia is comprised of:
  - **0.3 million km2 of territorial sea**.
  - **3.09 million km2 of archipelagic water**.
  - **2.97 million km2 of executive economic zone**.
  - This combined adds up to approximately 6.36 million km2 of marine area as per.
- The **coastline of Indonesia** is reported as **99,093 km** or **104,000 km**. This extensive tropical coastline provides an optimal habitat for marine life, including seaweeds.

Source: https://www.resourcefulindonesian.com/mapping-indonesia.html

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Vast and Underexplored Biodiversity in Indonesia

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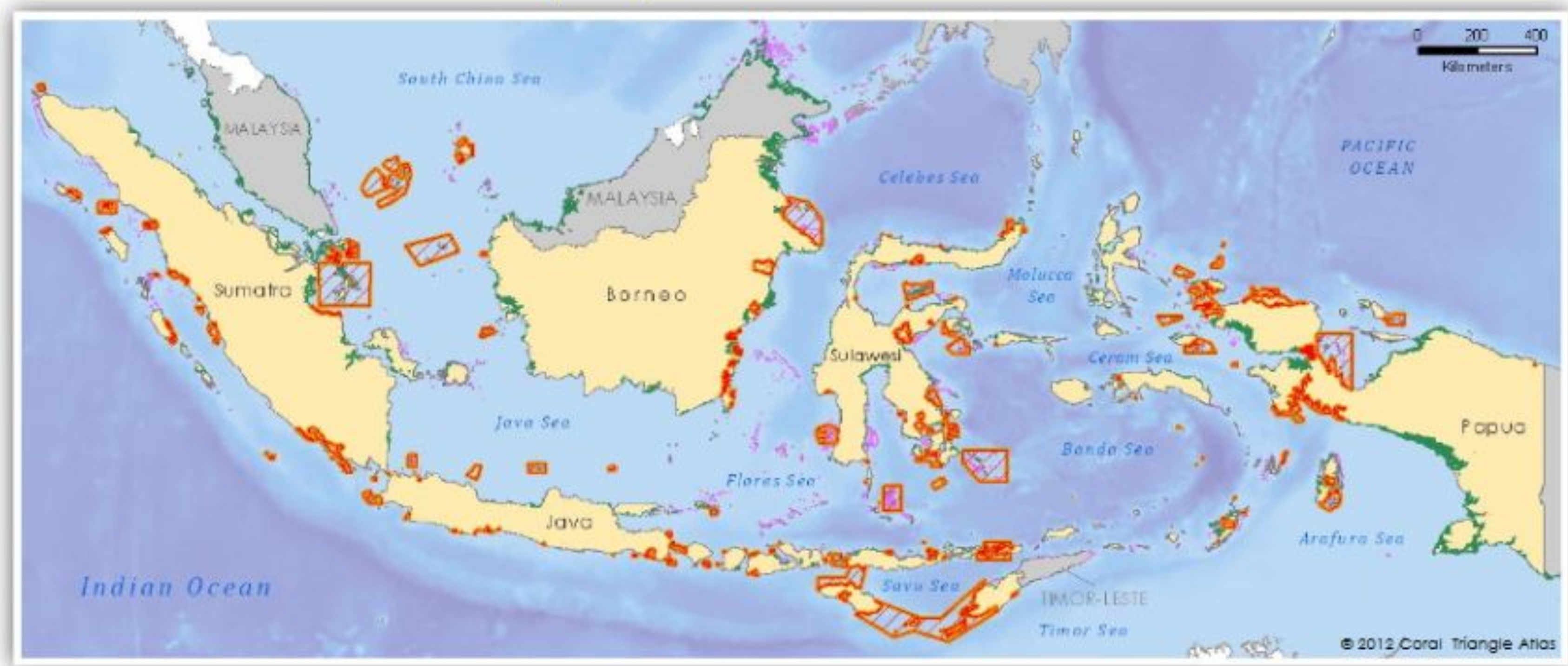
- Indonesia's waters are home to mega biodiversity, including plants, animals, and microorganisms. It boasts approximately 86,700 square kilometers of coral reefs, encompassing over 75% of the world's coral reef species.
- A systematic review identified at least 325 species of seaweed (103 green, 167 red, 55 brown algae), predominantly found in mangrove forests and coral reefs across numerous islands.
- Marine organisms, such as sponges (850 recorded species in Indonesia), ascidians, gorgonians, and various microorganisms (bacteria and fungi), are abundant and serve as rich sources of unique natural products.
- Despite this richness, a significant portion of marine species, especially microorganisms like marine fungi and bacteria, remain under-explored.

(Nugraha, et. al. 2023 & Basyuni, et. al. 2024)

INDONESIA



Number of **MPAs** (known boundaries)*	166 (166)
Total MPAs area (km^2) for known boundaries	187,221
MPAs in EEZ (%)	3.1
Coral Reef area (km^2)**	19,805
Reef area in MPAs (km^2)	6,291
Reefs in MPAs (%)	32
Mangrove area (km^2)***	29,631
Mangrove area in MPAs (km^2)	2,609
Mangrove in MPAs (%)	9

❑ **MPA Management Authority:**
- Directorate General for Marine Affairs, Coastal Areas and Small Islands
- Directorate General of Forest Protection and Nature Conservation Ministry of Forestry

❑ **Coral Reef:**
- Number of coral species (Veron *et al.*, 2009): 574

❑ **Mangrove:**
- Number of mangrove species (Spalding *et al.*, 2010): 45
- One of the world larger mangroves area and the largest in Asia (FAO, 2007)

*Compiled from various sources by CT Atlas team up to July 2012;
**UNEP-WCMC (2010) Global Distribution of Coral Reefs. Download from UNEP-WCMC's Ocean Data Viewer (http://data.unep-wcmc.org/datasets/13) and further correcting the topology error by CT Atlas team (2012);
***UNEP-WCMC (2010) Mangroves of the World 2010. Preliminary global dataset provided to ReefBase.

Source: http://ctatlas.coraltriangleinitiative.org/Country/Index/IDN

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Economic Opportunities and Industries in Indonesia

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Aquaculture and Fisheries:

- The marine sector is crucial for Indonesia's food security, supplying 70% of dietary protein to its population, and generating substantial annual revenue.
- **Indonesia** is a leading global producer in aquaculture, **ranking second worldwide in seaweed production after China, contributing 38% of the global seaweed market**. In 2021, estimated seaweed production reached 9.05 million tons.
- Biotechnology significantly enhances aquaculture, improving fish production, species quality, and disease resistance. This includes using synthetic hormones for breeding, chromosomal engineering, sex control techniques, transgenesis for improved traits, and biotechnologically enhanced feed and health management (e.g., vaccines and molecular diagnostic tests).
- Seaweed farming is a major source of income for coastal communities, requiring relatively low capital, and is frequently seen as a valuable supplementary revenue source. Commercial species like *Eucheuma*, *Kappaphycus*, and *Gracilaria* are cultivated for hydrocolloids such as agar and carrageenan, which have increasing global demand in food, pharmaceuticals, cosmetics, and biofuels. The Indonesian government is implementing a "Seaweed Down-streaming Policy" to boost the industry, including pilot projects and development of seaweed-based biofuels and biodegradable plastics.

Source:
https://thebalisun.com/communities-concerned-bali-farmers-are-returning-to-risky-tourism-sector-for-income/

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Economic Opportunities and Industries in Indonesia

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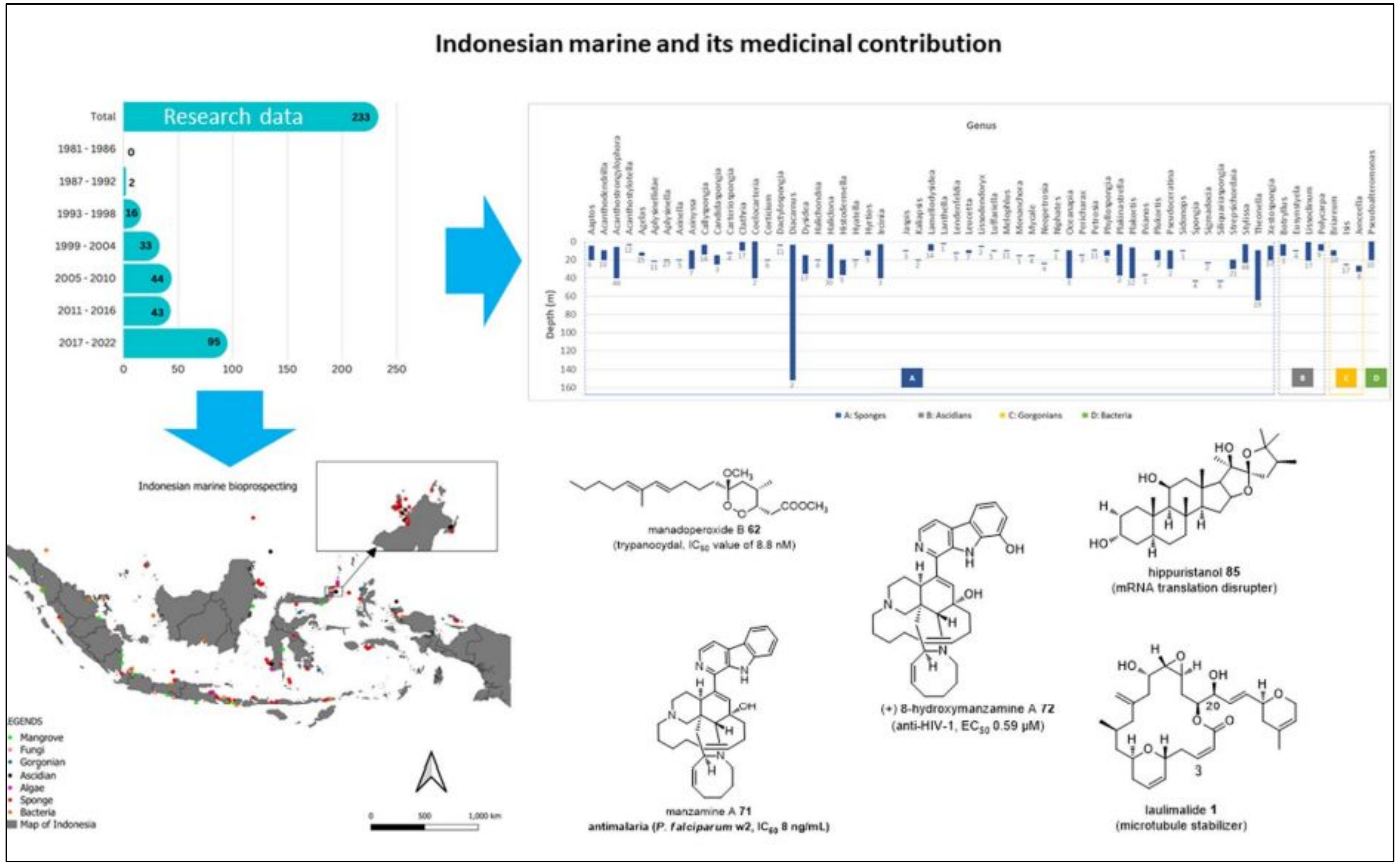
Biopharmaceuticals and Medical Treatment:

- Indonesia's marine organisms are a prolific source of bioactive natural products with diverse scaffolds and pharmacological activities.
- Compounds isolated from Indonesian marine organisms (sponges, ascidians, gorgonians, fungi, bacteria) have shown potent activities including anticancer, antimycobacterial (anti-TB), antidiabetes, antidyslipidemia, antiosteoblastogenic, anti-malarial, and anti-HIV-1 effects.
- Notable discoveries include: laulimalide (a potent microtubule stabilizer from *Hyattella* sp.), papuamine (a prospective doxorubicin complement from *Neopetrosia cf exigua* and *Haliclona sp.*), potent antiplasmodial manzamine A from *Acanthostrongylophora ingens*, highly potent anti-trypanosomal manadoperoxide B from *Plakortis cfr. Simplex*, mRNA translation disrupter hippuristanol from *Briareum* sp., and the anti-HIV-1 (+)-8-hydroxymanzamine A from *Acanthostrongylophora* sp..
- While no commercial drugs from Indonesian marine environments are currently on the market, the molecular diversity and understudied biodiversity reveal great promise.



(Source: Nugraha, et. al. 2023)

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Conclusion

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Marine biotechnology is rapidly advancing globally, led by significant R&D investment, especially from China, India, and South Korea. Key trends include a focus on sustainability, enhanced productivity, and the use of advanced omics and bioinformatics to explore marine biodiversity. Marine organisms offer immense potential for pharmaceuticals (e.g., laulimalide, papuamine), nutraceuticals, sustainable aquaculture, biofuels, and bioplastics. Marine microbes also provide valuable industrial enzymes. Realizing this potential requires strong global collaboration among governments, academia, industry, and civil society. Initiatives like Europe's Ocean4Biotech emphasize the need for transnational networks to overcome challenges such as high R&D costs, data standardization, and limited public awareness. Indonesia, with its vast marine biodiversity and rising synthetic biology initiatives, is well-positioned to contribute to the global marine bioeconomy, despite challenges in data access and conservation costs. Collaborative efforts are essential for a truly sustainable marine biotechnology future.

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