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Making marine biotechnology work for people and nature

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Transforming the rapidly growing ocean economy into a “blue economy” based on principles of sustainability, equity and inclusivity is crucial. We contend that marine biotechnology is not currently on this trajectory, and that a more holistic approach for people and nature is needed to bring marine biotechnology into the blue economy.

The ocean economy encompasses economic sectors as diverse as shipping, tourism and aquaculture, with a collective export value estimated at USD 2.5 trillion. Its global scale and rapid growth have triggered concerns due to the benefits remaining heavily concentrated within a handful of countries and companies, while degradation of ocean ecosystems affects all¹. This reality has spurred growing calls to transform the ocean economy into a “blue economy”, one that ensures ocean sectors are aligned with principles of sustainability, equity and inclusivity².

Marine biotechnology – the use of marine organisms to solve problems and make useful products – is one important sector of the ocean economy. It has generated a diverse and growing suite of innovations of central importance to multiple industries (Figure 1)³ and has great potential to become part of the blue economy³. Indeed, an inclusive and equitable marine biotechnology sector could also result in significant benefits to low and middle-income countries, which contain within their jurisdictions some of the world’s most biodiverse marine ecosystems. Likewise, the deep sea is a frontier of marine biotechnology interest found predominantly in areas beyond national jurisdiction, a vast global commons covering two-thirds of the ocean⁴.

50 Despite this great potential, marine biotechnology has been almost exclusively driven by
51 highly-industrialized countries and remains misaligned with blue economy principles of
52 equity and inclusivity⁵. Efforts to eliminate such inequities have relied on protracted
53 international negotiations that have yielded mixed outcomes, not least due to rapid
54 advances in biotechnology that dramatically outpace the development of appropriate
55 regulatory frameworks⁶. Here we argue that a singular focus on regulatory solutions could
56 result in the marine biotechnology industry remaining misaligned with the aspirations of a
57 blue economy, and that a more holistic approach for people and nature is crucial.

58

59 **Complexities and tradeoffs in marine biotechnology**

60

61 Marine biotechnology has frequently resulted in innovations that can contribute to
62 achieving sustainability goals, for example improvements in aquaculture production.
63 Genetically-engineered salmon grows twice as quickly and can thrive in near-freezing
64 conditions due to insertion of genes from two other fish species³. While such advances are
65 improving food yield, they can also encourage over-reliance on monocultures, and spatial
66 expansion of salmon pens into more coastal areas, potentially harming local and Indigenous
67 communities who rely on integrity of wild salmon populations³.

68

69 Another example of the complex trade-offs arising from marine biotechnology is the recent
70 development of transgenic canola plants with genes from a variety of marine and
71 freshwater algae⁹. Transgenic canola produces high levels of omega-3 fatty acids and could
72 become a key agrofeed ingredient, potentially reducing the need for fishmeal production
73 and relieving fishing pressure in low-income coastal regions, where fish is nutritionally vital
74 for local communities. Yet a trade-off would remain if increased demand results in further
75 conversion of land for monoculture canola production.

76

77 **A regulatory landscape struggling to keep up**

78

79 Substantial effort has been focused on regulatory instruments to address sustainability and
80 equity issues. Perhaps the most significant milestone for the biotechnology community was
81 the entry into force of the Nagoya Protocol in 2014, intended to eliminate inequitable and
82 unethical practices. These include biopiracy, which involves the appropriation of genetic
83 resources (and often associated traditional knowledge) from Indigenous peoples and local
84 communities and subsequent commercialization without sharing of benefits. The Nagoya
85 Protocol established a framework for “source” and “user” countries to regulate access to
86 genetic resources and subsequent benefit sharing according to mutually agreed terms.

87

88 The Nagoya Protocol, however, follows an overall pattern of policymaking being far
89 outpaced by scientific and technological advances⁵. During the 12 years that it was being
90 negotiated, for instance, the first synthetic life form was created, the CRISPR gene editing
91 technique was introduced, and cultivation of genetically modified organisms had spread to
92 over 10% of the world’s farmland⁵. As a tool most effective at regulating the movement of
93 physical samples across national boundaries, the Nagoya Protocol came into effect at the
94 same time that the industry was growing less reliant on physical samples and increasingly
95 working directly with genetic sequence data. Today, the industry applies a growing suite of
96 bioinformatics and omics technologies to analyze vast databases such as the GenBank

97 Sequence Read Archive. Since 1982, this database has been doubling in size roughly every
98 18 months¹⁰ as a result of the average cost of sequencing a base pair of DNA falling by six
99 orders of magnitude within two decades from over USD 6,000 in 2001 to less than USD 0.01
100 in 2020³.

101

102 Multiple negotiations are currently underway to better regulate access, use and
103 transparency requirements associated with marine genetic resources and genetic sequence
104 data, including in areas beyond national jurisdiction¹¹. While progressive regulatory
105 frameworks can help to clarify and level the playing field for all, sluggish regulatory
106 responses can result in a widening gap between those with the capacity to engage in marine
107 biotechnology and everyone else.

108

109 **Bringing marine biotechnology into the blue economy**

110

111 We contend that successfully transforming marine biotechnology into an element of the
112 blue economy will depend on coordinated actions by diverse actors, including scientists,
113 local communities, and companies. We suggest four interrelated pathways to accelerate this
114 transformation.

115

116 *1. Strengthen capacity in lower income countries*

117

118 An aspiration of the blue economy is that it can drive greater equity and inclusivity in the
119 ocean economy⁹. However, just ten countries account for 98% of filed patent sequences
120 from marine life⁵. This relates to capacity limitations, which are a particular barrier in the
121 case of the most lucrative biotechnology products. For example, it costs an estimated USD 1
122 billion³ to bring a new drug from development to market, and all marine drugs that have
123 been brought to market were developed by companies in Europe, Japan and North America.
124 For low and middle-income countries to fully benefit from marine biotechnology, efforts at
125 multiple levels are needed to develop capacity and close resource gaps. First, research
126 groups can contribute with efforts to strengthen human and technical capacity, and to
127 provide research and product development infrastructure that builds lasting ability to
128 develop solutions and foster change that aligns with national interests and priorities.
129 Second, the handful of companies driving innovations in the marine biotechnology sector⁵,
130 which are currently benefitting most from the ocean's genetic resources, should play a
131 similarly disproportionate role in ensuring that global sustainability goals and ocean equity
132 is achieved by advancing capacity building and transfer of marine technology. Third,
133 providers of development finance and philanthropies should dedicate more resources to
134 drive equitable outcomes, noting that SDG14 ("Life Below Water"), which includes Target
135 14.8 on increasing scientific knowledge, research and technology, receives the least
136 development funding of any of the Goals¹⁰. Finally, the international community should
137 elevate capacity building and the transfer of marine technology within the UN Decade of
138 Ocean Science for Sustainable Development 2021-2030 as well as the negotiations on a
139 treaty for biodiversity in areas beyond national jurisdiction to generate further institutional
140 support.

141

142 *2. Equitable and inclusive research collaborations*

143

144 Although industry is seen as the main commercial driver of marine biotechnology, academic
145 institutions are central players¹¹. Not only are they driving the exponential growth of
146 databases like GenBank by depositing sequence data from research expeditions, but many
147 universities also own and operate their own commercialization centers – private companies
148 established to monetize university research¹¹. Nearly one-third of patent applications
149 associated with marine genetic resources have been filed by universities or their
150 commercialization centers¹¹. The transboundary nature of many marine science topics has
151 spurred international collaboration, but may be strengthening imbalances rather than
152 challenging them¹² unless these collaborations ensure representative inclusion, rely on
153 working openly and in a transparent manner with a broad range of stakeholders in
154 developing solutions, and ensure that stakeholders from low and middle income countries
155 have an active voice and role in study design¹³. More explicit requirements from research
156 funders and scientific journals to disclose sample origin and acknowledge collaborators may
157 help shift existing norms¹⁴ toward more equitable collaborations.

158

159 *3. Commit to responsible data sharing*

160

161 While a broad landscape of environmental and genetic sequence databases already exists,
162 interoperability and access issues limit the potential for diverse groups to fully utilize these
163 resources. The UN Decade of Ocean Science for Sustainable Development aims to address
164 this issue, and acknowledges that data infrastructures need to be co-designed with
165 stakeholders to achieve the desired social and political impact¹⁵. Local authorities as well as
166 private companies can play crucial roles in supporting the flow of data through targeted
167 partnerships and investment focused on ensuring data accessibility and development of
168 technical capacity. Protracted and unresolved negotiations under the auspices of the World
169 Trade Organization have focused on new regulatory obligations to disclose the origin of
170 genetic samples being commercialized, which would add a layer of transparency and
171 accountability to such activities. Scientists involved in filing marine biotechnology patents
172 could advance best practices by disclosing origin of marine genetic resources throughout all
173 academic and commercial activities^{11,16}. While commitments to sharing marine genetic
174 sequence and origin data are crucial for transparency and can facilitate access and
175 engagement by as broad a set of constituents as possible, there is a tension between such
176 commitments and the protection of Indigenous rights and data sovereignty. In such cases,
177 attention should be paid to the International Indigenous Data Sovereignty Interest Group
178 who developed the ‘CARE Principles for Indigenous Data Governance’¹⁷ based around the
179 principles of Collective Benefit, Authority to Control, Responsibility, and Ethics. These
180 people- and purpose-oriented principles build on earlier data-centered work represented in
181 the ‘FAIR Guiding Principles for scientific data management and stewardship’ (Findable,
182 Accessible, Interoperable, Reusable) and represent a cornerstone of responsible data
183 sharing highly relevant in the context of genetic resources and marine biotechnology.

184

185 *4. Connect marine biotechnology to marine conservation*

186

187 Marine biotechnology can support local to global conservation efforts in multiple ways.
188 Examples include bioremediation and ecosystem monitoring, where the collection and
189 sequencing of samples from marine ecosystems can provide a baseline for taxonomic and
190 conservation efforts³. Biotechnology and genomic research are increasingly being used to

191 design ecosystem adaptation strategies, most prominently perhaps in efforts to create
192 bionic corals, including through CRISPR gene editing¹⁸. Better connecting biotechnology to
193 local conservation planning and outcomes can broaden the range of beneficiaries from this
194 industry and highlight the existential reliance of the marine biotechnology community on
195 intact and functioning marine ecosystems.

196

197 While the environmental impacts of sample collection can be minimal¹⁹ – marine natural
198 products are increasingly sampled through analytical chemistry rather than collection of
199 physical samples – an analysis of genetic sequences referenced in patents identified
200 multiple endangered and critically endangered marine species (Figure 2). Importantly, the
201 vast majority of species associated with marine biotechnology have not been assessed by
202 the IUCN (1,191 of 1,488 species). Responsible practice within such contexts of uncertainty
203 requires precautionary efforts, and provides further incentive to conserve entire
204 ecosystems, which can result in living repositories of genetic information with potential
205 future biotechnological potential.

206

207 **Conclusion**

208

209 While marine biotechnology has resulted in diverse benefits, more effort is needed to
210 ensure this sector does not perpetuate systemic injustices through stark discrepancies in
211 access, capacity and opportunities. The four interrelated pathways highlighted in this
212 commentary present opportunities to build lasting capacity where it is needed, to leverage
213 existing advances, and to accelerate progress towards ensuring the marine biotechnology
214 sector espouses the principles at the core of the blue economy. Crucially, these pathways
215 are viable irrespective of whether key international negotiations have stalled, or result in
216 regulatory frameworks that are easily sidestepped by bad actors. A status quo approach
217 may result in a marine biotechnology industry that remains profitable and continues to
218 deliver impressive scientific advances that benefit human well-being, but at its core, it
219 would be at odds with the larger aspirations of equity, sustainability and inclusivity inherent
220 to a blue economy, to the UN Decade of Ocean Science for Sustainable Development, and to
221 the Sustainable Development Agenda.

222

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224

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229 **Author contributions statement**

230 *All authors contributed to the writing and revision of the manuscript.*

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232 **Competing interests statement**

233 *The authors declare no competing interests.*

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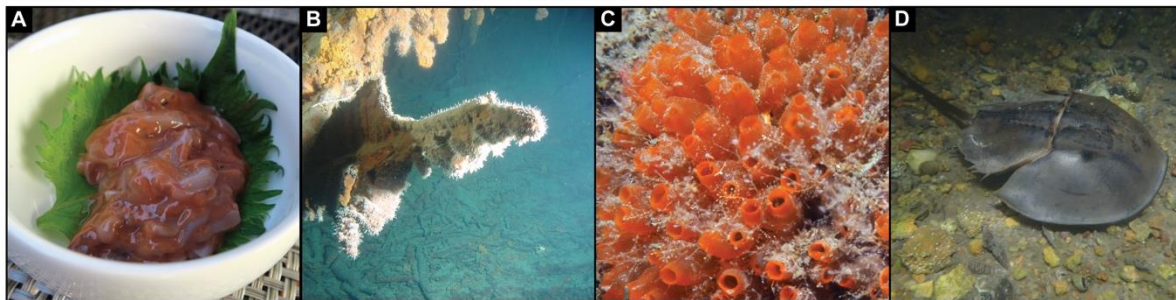
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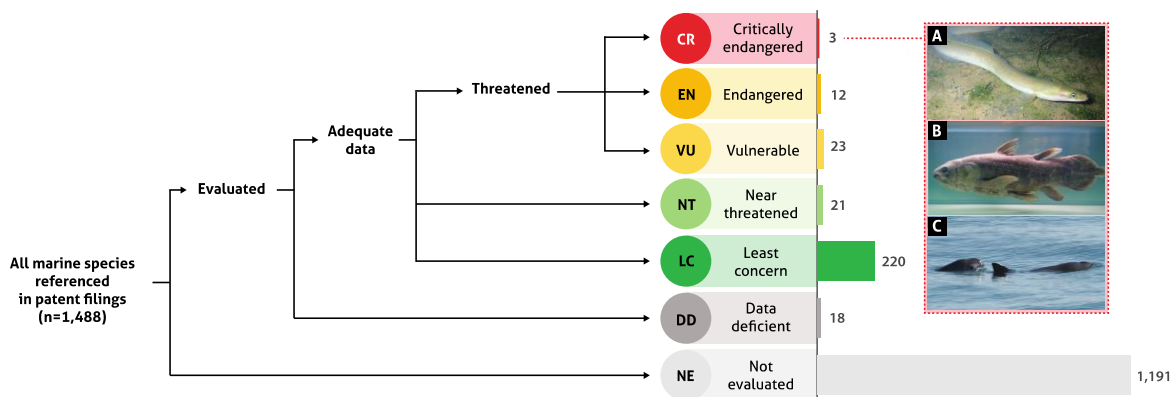
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291 **FIGURE 1: Commercialization of marine genetic resources** (A) *Bacillus jeotgali* was originally isolated
 292 from traditional Korean seafood jeotgal, and an associated strain has been identified as a potent
 293 bioremediating agent for polluted waterways⁷. (B) *Halomonas titanicae* was isolated from rusticles
 294 collected from the wreck of the Titanic and has been identified for its predicted functionality as a
 295 neurotransmitter to treat mental disorders⁸, (C) *Ecteinascidia turbinata*, a sea squirt found on mangrove
 296 roots in the Caribbean, is the source organism for the active ingredient Ecteinascidin-743 in the drug
 297 Yondelis, a treatment for advanced soft tissue sarcoma³. (D) *Tachypleus tridentatus*, a horse-show crab
 298 assessed as “Endangered” in the IUCN Red List, is a source of *in vitro* diagnostic reagent for invasive
 299 fungal infections prevalent in tropical regions. Photo credits: (A) [CCO Public Domain]; (B) Lori Johnston
 300 [NOAA-Public Domain], (C) Pauline Walsh Jacobson [CC BY 4.0]; (D) [CCO Public Domain].

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302

303 **Figure 2: Marine biotechnology and conservation.** Updating and expanding a previous analysis (see
 304 Supplementary Information), we identified sequences from 1,488 marine species referenced in patent
 305 filings. A total of 279 of the species have been assessed by the International Union for Conservation of
 306 Nature (IUCN), including species that are Near Threatened (21), Vulnerable (23), Endangered (12) and
 307 Critically Endangered (3). The latter category includes the (A) European eel (*Anguilla anguilla*), (B) West
 308 Indian Ocean coelacanth (*Latimeria chalumnae*) and (C) vaquita (*Phocoena sinus*). Photo credits: (A) Lara
 309 Maleen Beckmann [CC BY 4.0]; (B) Bruce Henderson [CC BY 4.0]; (C) Paula Olson [NOAA-Public Domain]