A Global Perspective: High-level analysis of key trends and developments in global marine biotechnology RTDI

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SUMMARY

A recent market research report[1] estimates that the global market for products resulting from marine biotechnology might exceed US$ 4B by 2015, of which marine biomaterials (including seaweed hydrocolloids) could contribute over 40%, and marine bioactives for healthcare would be the most important and fastest-growing sector. The size of this, even if it is an over-estimate, suggests that the harnessing of marine bioresources through biotechnology and development of products and services should be a serious target for any country with significant aquatic biodiversity. It is of interest that the report noted that very few countries have national marine biotechnology R&D programmes; it also identified the USA as the world leader in marine biotechnology.

That marine bioresources can give rise to specific molecules of tremendous use or potential for human medicine is undeniable. There are now 4 approved products, 13 in clinical trials and a large number in pre-clinical investigation[2], coming from a wide range of organisms from many different parts of the world. The route to market involves isolation and chemical characterisation, followed by synthesis or semi-synthesis of the molecule or an active analogue. Prialt® ziconotide, a painkiller originally isolated from a Pacific (Philippines) cone snail, Yondelis® trabectidin, an anti-cancer molecule from a Caribbean tunicate Ecteinascidia turbinata, and anabaseine (DMXBA) from the ribbon worm Paranemertes peregrina, from the Pacific Rim, are examples.

This CSA MarineBiotech report brings together as much information as can initially be found on national strategies for biotechnology and marine biotechnology, programmes and major research centres. It is intended to be a high-level overview and analysis of research, investments, research programmes and trends. It is also a 'living document', through the medium of the WIKI-pages of the MarineBiotech website[3] to be corrected, expanded and brought up to date by interested parties who have access to direct knowledge and accurate information. It is also intended to raise interest in transnational collaborative possibilities between European countries and others.

The countries that are the focus of this report include those that are relatively highly active, such as USA, Brazil, Canada, China, Japan, Republic of Korea and Australia, as well as others where activities are growing from a smaller base (Thailand, India, Chile, Argentina, Mexico, South Africa) and where there are signs that marine biotechnology is increasing in importance as a research priority. Multinational regional approaches and infrastructures are also included where appropriate. It is notable that the major international effort, the Census of Marine Life (CoML), involved 2700 researchers, about 31% from Europe, 44% from USA and Canada, and 25% from the rest of the world, notably Australia, New Zealand, Japan, China, South Africa, India, Indonesia and Brazil.

Perhaps the most important strategic move is that OECD is now involved in marine biotechnology considerations. OECD has established a steering group to develop a strategy for marine biotechnology, initiated by Norway in 2010 and now including Belgium, Canada, Denmark, France, Korea, Israel, Mexico, USA, the EU and the OECD's BIAC (Business and Industry Advisory Committee). In addition, OECD maintains an interest in facilitating the international networking of Biological Resource Centres, to ensure that collections are properly managed.

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1 *Marine Biotechnology: A Global Strategic Business Report* (2011) Global Industry Analysts Inc, San Jose USA - http://www.strategyr.com/Marine_Biotechnology_Market_Report.asp

2 Mayer AMS, Glaser KB, Cuevas C *et al.* (2010) The odyssey of marine pharmaceuticals: a current pipeline perspective *Trends in Pharma Sciences* 31 255-265 doi:10.1016/j.tips.2010.02.005

3 http://www.marinebiotech.eu

In summary, the work so far has shown the following:

Overarching science strategies, plans and policies

In **Africa**, Mozambique has a coherent biotechnology plan. Otherwise, only Nigeria, South Africa and Tunisia seem to have any elements of biotechnology or marine sciences plans, policies or strategies. Kenya launched a national bioprospecting strategy in 2011 in response to biopiracy.

In **Central & South America**, Brazil and Chile have national biotechnology plans. Chile also has a national Innovation Plan (2012-2014). Argentina's Law 26270 focuses on building the economy through facilitating biotechnology enterprise. Mexico has PECiTI (the national Science, Technology & Innovation programme), and a National Development Plan 2007-2012. No country has a marine biotechnology strategy, but Brazil carries out strategic R&D through a specific programme BIOMAR, established in 2005, and Costa Rica has an institute to manage the exploration and use of biodiversity, INBio, established in 1989.

In **North America**, Canada published its first National biotechnology strategy in 1983 and renewed it in 1998. Genome Canada was founded in 2000 as 'a catalyst for developing and applying genomic sciences that create economic wealth and social benefit '. The USA announced in 2011 a National Bioeconomy Blueprint. Neither country has a specific marine biotechnology strategy, plan or policy. The Canadian marine strategy of 2002 and Healthy Oceans Initiative of 2007 contain some elements that might be relevant but the overall focus is on sustainability and integrated approaches to oceans.

In **Asia**, four of the most important players in marine biotechnology can be found, China, India, South Korea and Japan. Taiwan, Korea, Japan and India have specific national biotechnology strategies; in China, biotechnology is an integral part of the Five Year Plans. Individual Indian states have also established biotechnology policies (Gujarat for example). There are no separate national marine biotechnology strategies or policies except in Korea, where there is Blue-Bio 2016. In other major countries, marine biotechnology is mentioned as a specific topic in strategic plans or programmes (such as China, Japan's BioStrategy 2002 or India's 11th Five Year Plan). India also has a National Policy on Biofuels (2009) to which marine biotechnology is contributing. Korea has a plethora of strategies, policies and plans and marine biotechnology is an explicit part of the Biotechnology Fostering Policy.

In the **Middle East**, there appear to be no national biotechnology or marine biotechnology strategies, policies or plans. Israel had an economic development Bio-Plan 2000-2010.

In **South-East Asia and the Indian Ocean Islands**, Thailand and Vietnam stand out as the countries most focused on marine biotechnology. Indonesia, Malaysia, Singapore, Sri Lanka, Vietnam and Thailand have national biotechnology strategies, plans or policies. Only The Philippines, with NARRDS, the National Aquatic Resources Research & Development System, and Vietnam, with a recently-issued letter from the President of VAST (Vietnam Academy of Science and Technology) explicitly calling for increased efforts in marine biotechnology, have anything resembling a marine biotechnology policy or strategy.

In **Australia-Pacific**, both Australia and New Zealand have biotechnology strategies but neither has a specific marine biotechnology strategy. In New Zealand, the Biotechnology strategy includes marine biotechnology within environment/industry, and MoRST (Ministry of Research Science and Technology) produced a roadmap for biotechnology research in 2007, which included marine biotechnology as a specific component. In Australia, enhancement of access to marine resources and marine science are mentioned in the National Biotechnology Strategy (2000-2008) and its successor '*Powering Ideas – An innovation agenda for the 21st century*', but marine biotechnology is not explicitly included. Australian States including Queensland and Tasmania do however include marine biotechnology as part of their research and economic development strategies. Marine Innovation South Australia includes and Aquaculture, Biotechnology and Biodiscovery Science group. Of the Pacific Islands, Guam and Fiji seem the most active in marine biotechnology. There are no obvious national strategies, but Fiji was an early mover in biodiversity (Access and Benefit-Sharing) policy development.

Research funding schemes and programmes

In **Africa**, Tunisia seems most forward in creating a programme that utilizes the relevant expertise of national research institutes.

In **Central & South America**, national schemes and programmes, with the exception of Brazil's BIOMAR, are generic, though many of them do support marine biotechnology. BIOMAR began road-mapping marine biotechnology in Brazil in 2007. It is a good case study for national marine biotechnology support programmes. Marine biodiscovery is recognized in Costa Rica's Bioprospecting programme (1991).

In **North America**, Fisheries and Oceans Canada has a strong programme in aquatic biotechnology and genomics and the National Research Council supports the Institute for Marine Biosciences in Nova Scotia. Genome Canada, through its regional activity in British Columbia, is a partner in the international Salmon Genome project and has other fisheries and environmental activities that are relevant for marine biotechnology. Québec supports the Marine Biotechnology Research Centre in Rimouski, which is an industry-facing development organization. In the USA, the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the Department of Energy and Department of Defense support aspects of marine biotechnology, the last 2 focusing strongly on algal biofuels. NSF was the main supporter of the enormous Microbial Observatories programme, and NOAA has 3 relevant programmes, national Sea Grant, Ocean Explorer and National Undersea Research.

In **Asia**, marine biotechnology is a specific part of China's National Hi-Tech R&D Programme '863'. The Chinese Academy of Sciences and Chinese government support Key Laboratories, some of which are focused on topics relevant to marine biotechnology. In India, DBT, the Department of Biotechnology, has a Task Force on Aquaculture and Marine Biotechnology, set up in 1998, which has funded over 200 projects since then. Japan was a leader in the area, establishing the Marine Biotechnology Institute in 1990, a public-private partnership, the lasting legacy of which appears to be only the national culture collection. Korea's Marine Bio 21 project (2004) has generated two genomics programmes, and the National S&T Plan 2008-2012 has Core technologies for New Industry: Marine Organism Conservation and Marine Biotechnology as one of its 7 investment areas.

In the **Middle East**, marine biotechnology seems to be fragmented and buried inside national research plans and programmes.

In **South-East Asia and the Indian Ocean Islands**, there is evidence of strong investment in biotechnology, but less so in marine biotechnology. The Ninth Malaysia Plan 2006-2010 allocated almost US$550M to industry development through biotechnology and Thailand's National Biotechnology Policy Framework (2004-2009) allocated about US$125M to biotechnology. There are few specific programmes involving marine biotechnology; one is the PharmaSeas Drug Discovery program, funded by the Philippines under NARRDS (National Aquatic Resources Research & Development System). Indian Ocean islands are sometimes involved in marine biotechnology activities, notably Madagascar, but more information is needed.

In **Australia-Pacific**, Australia's 'Super Science Initiative' plans to put A$1.1B into innovation science 2009-2013, approximately 45% into biotechnology, including marine biology in one of the 'Future Industries' themes. Australia already supports a world-class basic and applied research institute, AIMS (Australian Institute of Marine Sciences). Australia has also established the Industrial Transformation Research Program in 2011, with $236M funding, though it isn't yet clear how much of this might be applied to marine biotechnology.

Research priorities

In **Africa**, biofuels and marine bioactives are the main research priorities. Aquaculture is important but there is not so much evidence of biotechnology applications as part of national programmes (see though Nigeria).

In **Central & South America**, the focus is very broad, including biodiscovery, bioenergy, bioremediation and biofouling. In Chile, there is also activity in molecular aquaculture, because of the importance of this sector to the economy. There are numerous universities and research centres involved in marine biotechnology in Brazil, Chile and Mexico.

In **North America**, although there is effort on biodiscovery and other aspects of marine biotechnology, including molecular aquaculture in Canada (salmon) and Atlantic Coast of USA (shellfish), the picture is heavily skewed by Dept of Energy and Dept of Defense support for algal biofuels, and private investment in algal biorefineries. There are individual units and centres with a strong marine biotechnology focus (Harbor Branch, Scripps, Bigelow and Maryland spring to mind). Most recently, the state of North Carolina has established a Marine Biotechnology Center of Innovation as part of its economic development plan.

In **Asia**, there is also a broad range of topics across the countries. There is an increasing focus on biofuels in India but elsewhere, biodiscovery for human pharmaceuticals, food, feed and cosmetics is predominant. The Korean Institute of Ocean Science and Technology is a world-leader in marine biosciences and biotechnology. There are numerous institutes, research centres and universities in China, India and Korea substantially involved in marine biotechnology but they do need more complete profiling to understand how competitive they are with European activities and whether there are broader opportunities for international collaboration.

In the **Middle East**, it is difficult to see what research topics might predominate. Israel is involved in sponge biotechnology, marine bioactives and marine biofuels. Turkey has activities in bioactives and in algal culture for bioenergy and biorefineries. Individual institutions are involved in a number of EU-funded consortia in marine biotechnology. Oman hosts the UNESCO chair in Seafood Biotechnology, at Sultan Qaboos University. There are probably new opportunities for algal biotechnology and molecular aquaculture in the region.

In **South-East Asia and the Indian Ocean Islands**, much of the focus seems to be on exploitation of natural biodiversity for novel bioactives. In Vietnam and Thailand, there is however significant molecular aquaculture, especially for crustacea (shrimps, prawns). Regionally-important research resources include University of Diponegoro Indonesia, the University of the Philippines Marine Science Institute and UP-Visayas, Thailand's National Center for Genetic Engineering and Biotechnology (BIOTEC), the Center of Excellence for Marine Biotechnology at Chulalongkorn University Bangkok, and several institutes within the VAST network in Vietnam.

In **Australia-Pacific**, the New Zealand Ministry of Research, Science & Technology's roadmap for biotechnology research recognises molecular aquaculture and marine bioactives as two of New Zealand's research strengths.

Infrastructures and coordination and support capacities/initiatives

In **Africa**, the Mediterranean Science Commission (CIESM), the Inter-Islamic Science and Technology Network on Oceanography (INOC) and the Ocean Data and Information Network of Africa are three notable integrational initiatives with involvement in marine biosciences.

In **Central & South America**, the best examples of academic infrastructure and support are to be found in Brazil, the government-funded networks RedeAlgas (macroalgae), Rede interinstitucional de algas bentônicas (microalgae) and Rede Brasileira de Tecnologia de Biodiesel (biodiesel).

In **North America**, there are some regional initiatives (ArcticNet in Canada, GulfBase in the USA for example) but the most important US-stimulated contribution to international support for marine biotechnology has been the Census of Marine Life (CoML).

In **Asia**, linkages are mainly attained through organised structures such as the key laboratories of China. In India, the Department of Biotechnology created a national Algal Biofuel Network in 2008.

In the **Middle East**, CIESM and INOC represent the most important trans-regional activities; CIESM brings eastern Mediterranean countries together with North African and southern European countries; INOC brings the Middle East into contact with other Muslim nations spread across the world.

In **South-East Asia and the Indian Ocean Islands**, the Association of South East Asian Nations (ASEAN) may assist in trans-regional activities but this is not clear. The Indonesian Dept of Marine Affairs and Fisheries established a scientific forum for Indonesian Marine Biopharmaceuticals in 2005, and in Vietnam the Ho Chi Minh City Biotechnology Park was started in 2010, with the intention of housing biotechnology start-ups in the aquaculture, seafood and environmental sectors.

In **Australia-Pacific**, the Australian Cooperative Research Centres (CRCs) provide translational services for industry and several of these have taken part in marine biotechnology-orientated work, in seafood genetics, Antarctic microbiology and bioremediation.

International activities

The Working Party for Biotechnology of OECD (the Organisation for Economic Cooperation and Development) established a work group in the area of marine biotechnology in 2010 as part of OECD's biotechnology policies activities, with considerable input from Canada, Norway, South Korea, Belgium, Switzerland and the OECD's BIAC (Business and Industry Advisory Committee). This work has taken place within the context of OECD's report 'The Bioeconomy to 2030)[4]. The OECD marine biotechnology Global Forum in Vancouver in May 2012 moved this area forward and established marine biotechnology development and valorization as a specific project for forthcoming OECD action. The Forum report is about to be published (end 2012-beginning 2013).

The EU is a strong actor in promoting and supporting international links. The review of 59 marine-related projects supported by EU funding, of which 16 are more closely biotechnology-associated, reveals that 14 of those with explicit marine biotechnology or genomics involvement include 26 different research institutions or companies in 18 different countries as consortium partners[5]. In addition, the EU's Joint Research Centre maintains a useful web-site listing research structures and policies around the world (http://erawatch.jrc.ec.europa.eu/erawatch/opencms/information/country_pages/). Many of the countries with potential for collaboration with EU institutions and companies in marine biotechnology, or in which the EU could have a favourable impact by capacity-building, are ICPC (International Cooperation Partner Countries) ftp://ftp.cordis.europa.eu/pub/fp7/docs/wp/cooperation/cooperation-general-annexes201101_en.pdf. Strategic recommendations for Horizon 2020 projects involving marine biotechnology might include nominations of appropriate countries as ICPCs for specific calls.

The EU-US Task Force on Biotechnology research has had several conferences on marine biotechnology topics, one of those in collaboration with CIESM.

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4 *http://www.oecd.org/futures/long-termtechnologicalsocietalchallenges/42837897.pdf*

5 European Commission (2011) *Interim Catalogue of Marine-Related Projects (2007-2010)* available at ec.europa.eu/research/bioeconomy/pdf/marine_2011_v11.pdf

Meeting the innovation challenge

In addition to funded projects and programmes that tackle specific areas of marine biotechnology, clusters and networks are recognised as tools to enhance the knowledge transfer that can lead to more efficient innovation. Examples include the joint EU-US Task Force on Biotechnology, the Mediterranean Science Commission CIESM or the Brazilian network RedeAlgas.

Innovation appears to be effected by a four-fold mechanism in the field of marine biotechnology. One is the drive to exploit a country's biodiversity sustainably, another is to join the trend for algal bioenergy and a third is to regard the marine sector as one that can be used as part of a general improvement in biotechnology capability in a country. The fourth, enhancement of food production from the seas through aquaculture, is well-established in those countries which have strong export markets for farmed fish and shellfish and is beginning to become more important in other countries where raising the general nutritional level of the population is important.

The CoML showed the power of public-private partnerships for moving marine biosciences forward. Without the intensive financial support of the Alfred P Sloan Foundation, this US$650M 10-year project would not have got off the ground. The involvement of OECD's Business and Industry Advisory Committee in the marine biotechnology initiative signals a serious intent in marine bioexploration for sustainable economic growth. Slow emergence of interest in aspects of marine biotechnology as economic drivers can be seen elsewhere, with new institutes (Marine and Microbial Biotechnology in India), industry-facing activities (CRCs in Australia, the Biotechnology Research & Development Center in Quebec, the Marine Biotechnology Center of Innovation North Carolina, the Marine Biological Products Industry Strategic Alliance announced in China in 2012, Indian State Government marine biotechnology parks) or translational networks (RedeAlgas in Brazil, the Algal Biofuels network in India).

Specific trends in strategy and policy are more difficult to bring into focus, and would be more suitable for updating via the envisaged MarineBiotech InfoPages[6].

Trends

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[6] See www.marinebiotech.eu

[7] See www.marinebiotech.eu

INTERNATIONAL and REGIONAL ACTIVITIES and INFRASTRUCTURES

ACP-ST

The EU's programme of support for the African, Caribbean and Pacific Group of States (ACP) has a Science & Technology programme, ACP-ST http://www.acp-st.eu. In a biofuels programme involving Namibia, Ghana and South Africa, marine algae are being investigated in Namibia http://www.acp-st.eu/content/capacity-building-south-africa-namibia-and-ghana-create-sustainable-non-food-bio-oil-supply-.

ANZMBN

ANZMBN http://www.flinders.edu.au/medicine/sites/marine-bioproducts/marine-biotech-network.cfm (the Australia-New Zealand Marine Biotechnology Network) was established in 2012 as a communication device between marine biotechnology research groups in Australia and New Zealand and is coordinated by Flinders University Australia and Waikato University New Zealand.

ARCTIC and ANTARCTIC REGIONS

Most marine biotechnology in polar regions is conducted by individual states alone or in ad hoc collaboration. There is no unified science, technology and innovation programme.

The Arctic Council has a working group on sustainable development that seeks to advance opportunities in the Arctic without damaging either biodiversity or the economies, culture and health of indigenous peoples http://www.arctic-council.org/index.php/en/sdwgeng. The Arctic Council's working group on Conservation of Arctic Flora and Fauna CAFF has a Marine Ecosystem Monitoring activity and has produced a Monitoring Plan for Arctic Biodiversity http://www.caff.is/. The Marine Steering Group members include Canada, Norway, the USA, Greenland, the Faroe Islands, Iceland and Russia.

Arctic bioprospecting and biotechnology activities have been conducted by Canada, the UK, Russia, the Scandinavian countries, Italy, Republic of Korea and China; other countries including Poland, India and Germany have engaged in biodiscovery using Arctic biota. Norway has the best-developed activities. Some organised collaborative work has been carried out, for example the KAIRA project, on bioremediation of Arctic mine waters, which involved companies and research organisations from Finland, the Netherlands and Sweden, with support from the European Regional Development Fund (http://www.metla.fi/hanke/7207/kaira-loppuraportti.pdf). The Russian Federation, UNEP and the Global Environmental Facility undertook a pilot study 2005-2007 to establish the use of brown seaweeds and marine microbes as off-shore de-pollutants for on-shore oil and hydrocarbon activities.

The University of the Arctic has established the Northern Research Forum (http://www.uarctic.org/singleArticle.aspx?m=717&amid=7914), but this does not seem to be working in industrial and marine biotechnology uses and developments of Arctic marine bioresources.

The International Polar Year 2007-2008 had research programmes that stimulated multinational projects involving Arctic and Antarctic environments http://www.ipy.org/. The IPY included POMIDIV, the Project on Polar Microbial Diversity, a collaboration between researchers from Japan, Belgium, Canada, the UK and Australia, which was part of a larger project MERGE (Microbiological and ecological responses to global environmental changes in polar regions. PAME, the Polar Aquatic Microbial Project, involved Canada, the USA, Argentina, Norway and the Russian Federation as well as 8 EU Member States. Since then, there have been 2 IPY conferences.

Antarctica is subject to international treaty concerning mutuality and prevention of exploitation by individual countries (the Antarctic Treaty of 1959, which came into force in 1961 http://www.antarctica.ac.uk/about_antarctica/geopolitical/treaty/update_1959.php).The original

signatories were Australia, Argentina, Belgium, France, Chile, Japan, Norway, New Zealand, the USSR, the UK, the USA and South Africa. A further 34 countries have acceded to it. It explicitly fosters international scientific collaborative research and preservation/conservation of biodiversity but does not address commercialisation. Antarctic bioprospecting is carried out by many countries, but notably Japan, USA, Spain, UK, China, Poland, France, New Zealand, Chile and India. SCAR (the Scientific Committee on Antarctic Research http://www.scar.org/) is part of the International Council for Science. SCAR's action groups include SCAR-MarBIN, the Antarctic Marine Biodiversity Network http://www.scarmarbin.be/. SCAR has also produced a code of conduct for sub-glacial aquatic exploration and research http://www.scar.org/treaty/atcmxxxiv/ATCM34_ip033_e.pdf.

The Antarctic Biological Prospecting Database contains information on 218 records of patents or commercialisation of Antarctic biodiversity, including use of krill and krill extracts, marine natural products for anti-cancer, anti-inflammatory, antimicrobial and immunomodulation purposes, and applications of psychrophiles in foods (http://www.bioprospector.org/bioprospector/antarctica/home.action). The majority of exploitation activity concerns Antarctic krill *Euphausia superba*, and the countries involved in most of the exploitation, as determined by patent activity, are Japan and USA. A report presented to the Antarctic Treaty Consultative Meeting 17 in Kyiv Ukraine 2008 noted over 40 companies involved in Antarctic biodiversity development and commercialisation, and about 20 universities or research institutions from around the world[8] http://www.bioprospector.org/bioprospector/Resources/actm/Atcm31_wp011_e.pdf.

ASEAN

The Association of Southeast Asian Nations Economic Community's Blueprint includes biotechnology and marine science as two of its main themes. The Science and Technology programmes (http://www.aseansec.org/19592.htm) supporting this also involve international collaborations such as the ASEAN-Australia Living Coastal Resources project, and 2012 is also the ASEAN-EU year of Science, Technology and Innovation.

ASIA BIOMASS OFFICE

The ABO (Asia Biomass Office) Japan hosts the Bio-fuel database for East Asia http://www.asiabiomass.jp/biofuelDB/index.html. The database was set up as a project of the Japan National Energy Foundation's Cooperation Initiative for Clean Energy and Sustainable Growth and is led by the Philippines. The database includes information on energy policy, biomass availability and energy generation activities for 13 Australasian countries, with 3 more to be added. The focus is mainly on agricultural outputs and waste materials but this resource could become of regional importance for algal biomass energy information.

AUF

AUF (the Agence Universitaire de la Francophonie) has one or two projects involving aquaculture but could be a stronger force for marine biotechnology across a large part of Africa, the Caribbean and South-East Asia. It has 55 francophone member countries and, by virtue of international academic partnerships, a further 43 collaborating countries. http://www.auf.org/

BioEuroLatina

BioEuroLatina (the Association for development of biotechnology in Latin America in cooperation with Europe) is or was a forum for collaboration and techno-economic lobbying http://www.bioeurolatina.com. It was established in Madrid in 2005. Its policy and support partners include Spain's Education and Science Ministry and CSIC, Catalunya's IRTA agrifood institute, and the European Commission; other partners include industry associations, biotechnology clusters and Banco Santander. It is not clear if this organisation is still active or whether its remit could include marine as well as land-based biotechnology.

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[8] *An update on biological prospecting in Antarctica, including the development of the Antarctic Biological Prospecting Database* XXXI ATCM Kyiv Ukraine, 2008, agenda item ATCM 17, WP-11

CIESM

CIESM (the Mediterranean Science Commission) was founded in 1908 and formally constituted in 1919, under the leadership of Prince Albert I of Monaco http://www.ciesm.org/. Egypt, France, Greece, Italy, Monaco, Spain, Tunisia and Turkey were founder members. There are now 22 members (http://www.ciesm.org/online/institutes/IndexInstituts.htm) and the 45th International Research Workshop was held in 2012. Aspects of marine biotechnology have been covered by CIESM in its workshops since 1997, most recently looking at Mediterranean marine extremophiles http://www.ciesm.org/online/monographs/index.htm. Of CIESM's six committees, C4 works on marine microbiology and biotechnology. There are currently no specific research programmes in marine biotechnology but a recent report examined the role of blue biotechnology in answering a number of specific challenges in the Mediterranean marine ecosystem[9]. Subjects included integration of marine biotechnology and nanotechnology for control of ship ballast water bio-pollution; marine biomolecules for chemistry, health, cosmetics, flavours and fragrances and vaccine adjuvants and stabilisers; new marine biomaterials and polymers.

CoML

CoML (the Census on Marine Life) was established by funding from the Albert P Sloan Foundation and spans the decade 2000-2010, involving over 80 countries, 540 expeditions, 2700 researchers, 30 million species-level records, and US$650M in funding support http://www.coml.org/. CoML created the Global Marine Life Database or OBIS (the Ocean Biogeographic Information System) http://www.iobis.org/. This links marine species with their oceanographic and ecological data. CoML has 17 projects from Abyssal Plains to Zooplankton and it is affiliated to other projects include WoRMS (the World Register of Marine Species http://www.marinespecies.org/about.php) and the Marine Barcode of Life http://www.marinebarcoding.org/, which are essential tools for checking new isolates against existing records. CoML has contributed almost 100,000 pages on marine species to the Encyclopaedia of Life http://eol.org/, and has a legacy function as the marine component of GBIF (the Global Biodiversity Information Facility http://www.gbif.org/). CoML and OBIS worked with AIMS Australia and the US's NOAA to create CReefs (the Census of Coral Reef Ecosystems), which has an Autonomous Reef Monitoring Structures programme providing real-time information on reef biodiversity http://www.creefs.org/.

CTI-CFF

CTI-CFF (the Coral Triangle Initiative on coral reefs, fisheries and food security) is a partnership of the Philippines, Malaysia, Indonesia, Timor-Leste, Papua New Guinea and the Solomon Islands, which is developing regionally-applicable approaches to biodiscovery, sustainable biodiversity use and equitable benefit-sharing for marine, freshwater and land-based resources in the 6 partner countries http://www.coraltriangleinitiative.org/. Although primarily concerned about protecting natural resources and responding to climate change, the initiative appears relevant for regional marine biotechnology.

CYTED

CYTED (the Ibero-American Programme for Science, Technology and Development) was set up in 1984 http://www.cyted.org/?lang=en. It is currently funding a network for development of the use of marine algae, coordinated by the Sociedad ibero-americana de algología aplicada (SI3A) and involving 28 organisations (universities, research centres, companies and an industry association) in 10 countries, including Spain, Portugal; Argentina, Brazil, Chile, Colombia, Ecuador; Costa Rica, Cuba and Mexico http://www.cyted.org/cyted_investigacion/detalle_accion.php?un=e0ec453e28e061cc58ac43f91dc2f3f0&lang=en.

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[9] *Ed.* Briand F (2011) *New Partnerships for Blue Biotechnology Development: innovative solutions from the sea* Proc CIESM Int Workshop Monaco 11-12 Nov 2010

EU-US Task Force on Biotechnology Research

The EU-US Task Force on Biotechnology Research was formed in 1990 by the European Commission and the US Office of Science and Technology http://ec.europa.eu/research/biotechnology/eu-us-task-force/index_en.cfm. The aim is to create synergies and coordinated efforts in exploiting biotechnology advances. It held a workshop on Marine microorganisms and research issues for biotechnology in 1996 in Brussels and another in collaboration with CIESM in 2008 on the interface between marine genomics and biotechnological applications. Most recently, a workshop on marine genomics and next-generation sequencing was held in Washington USA in 2010. Other workshops have been held on environmental biotechnology that include aspects of microbiology, genomics and bioremediation of relevance to Blue Biotech[10].

ESTNET

The Economic Commission for Africa was founded by the UN in 1958 to help policy makers and others with an interest in science and technology related business, and enhance S&T policy capacity; most if not all African states are members. It operates the ECA Science and Technology Network ESTNET http://www.uneca.org/estnet/about/aboutus.htm, which also provides information on government ministers and the heads of other significant organisations in each country, via a clickable map http://www.uneca.org/estnet/index.htm.

GULFBASE

GulfBase provides information about projects carried out in the US States, Cuba and Mexico concerning the Gulf of Mexico and the Gulf-Atlantic zone http://www.gulfbase.org/. Although the majority of these projects are ecological, some are oriented towards sustainable use of marine bioresources, including biotechnology projects.

ICBG

ICBG (the International Cooperative Biodiversity Groups) operates a programme to explore and utilise the world's biodiversity for medical purposes http://www.icbg.org/index.php. The sponsors are a number of US Government bodies, including the National Oceanic and Atmospheric Administration NOAA, the National Institutes of Health NIH, the National Science Foundation NSF and the Department of Agriculture and Energy (USDA and DoE). The Fogarty International Centre is the coordinator of the ICBG http://www.fic.nih.gov/Programs/Pages/biodiversity.aspx. Current and previous projects within the ICBG Program include many with marine-related aspects, such as development of marine biodiversity in Fiji, natural product discovery in Costa Rica, drugs from marine molluscs in the Philippines and bioactives from Jamaican reefs http://www.icbg.org/groups/.

ICRAN & ICRI

ICRI (the International Coral Reef Initiative) is an alliance of governments, non-governmental organisations, and international biodiversity and ecology organisations, arising from CBD discussions in 1994 http://www.icriforum.org/. Although its main purpose is to conserve and restore coral reefs, part of its remit is to encourage sustainable use of coral reefs and related bioresources. Australia and Belize co-chair the ICRI Secretariat for 2012-2013. ICRAN (the ICRI Action Network) is a network of reef scientists and conservation organisations and supports ICRI's implementation projects and aims http://www.icran.org/index.html. It was set up in 2000 with a grant from the United Nations Foundation and is involved in training, education, capacity-building, information-gathering and develops regional as well as national initiatives http://www.icran.org/action.html.

[10] See http://ec.europa.eu/research/biotechnology/eu-us-task-force/index_en.cfm?pg=workshop_past for more information on past workshops in a wide range of subjects – reports where available can be downloaded from this site.

ICSU

ICSU (the International Council for Science) plans and coordinates international research programmes, some of which have relevance to marine biotechnology, biodiversity and ecology http://www.icsu.org/. These include SCAR (Antarctic Research), DIVERSITAS (Biodiversity) and SCOR (Ocean research). There is no specific marine biotechnology programme.

INOC

INOC (the Inter-Islamic Science and Technology Network on Oceanography), organizes conferences and coordinates research vessels across Africa, Asia and the Middle East http://www.inoctr.org/index.html. Members include 19 countries (Algeria, Bangladesh, Cameroun, Egypt, Indonesia, Iran, Iraq, Jordan, Lebanon, Malaysia, Mauretania, Morocco, Pakistan, Saudi Arabia, Senegal, Syria, Tunisia, Turkey (the current chair) and Turkmenistan, with Northern Cyprus as observer. INOC held an International Symposium on Marine Ecosystems, Natural Products and their Bioactive Metabolites in October 2011, in Bogor, Java.

IODE

IODE (the Intergovernmental Oceanographic Commission of UNESCO), was established 1961 to "enhance marine research, exploitation and development, by facilitating the exchange of oceanographic data and information between participating Member States, and by meeting the needs of users for data and information products" http://www.iode.org/. IODE operates a number of regional Oceanography Data and Information Exchange Networks. IODE and its regional mirror organisations are important as collators and providers of oceanographic information essential to marine biodiscovery, environmental biotechnology and other aspects. IODE runs the OceanExpert network, a directory of scientists and other professionals http://www.oceanexpert.net/.

NAMSIC

NAMSIC (the North African Marine Science Institutes and Centers Network) was established in 2008 and includes institutions in Algeria, Libya, Mauretania, Morocco and Tunisia. It is not clear if it has developed beyond an initial meeting or whether it includes marine biotechnology and bioresources development in its remit.

ODINAFRICA

ODINAFRICA (the Ocean Data and Information Network of Africa) provides fundamental information on projects and people involved in marine and freshwater activities http://www.odinafrica.org/. It hosts AFRIDIR (the African Directory of Marine and Freshwater Professionals http://www.odinafrica.org/index.php?option=com_content&view=article&id=3&Itemid=4). The network includes over 40 marine institutions from 25 countries and is supported by UNESCO's Intergovernmental Oceanographic Commission and the Government of Flanders, Belgium.

OECD

The Working Party for Biotechnology of OECD (the Organisation for Economic Cooperation and Development) established a work group in the area of marine biotechnology in 2010 as part of OECD's biotechnology policies activities http://www.oecd.org/sti/biotechnologypolicies/marinebiotechnologyattheoecd.htm. Prime movers in this are the delegates of Canada, Norway, South Korea, Belgium, Switzerland and the OECD's BIAC (Business and Industry Advisory Committee). The Global Forum in Vancouver in May 2012 moved this area forward and established marine biotechnology development and valorisation as a specific project for forthcoming OECD action http://www.oecd.org/sti/biotechnologypolicies/forumonmarinebiotechnology30-31may2012agendaandpresentations.htm. Attendees came from the 34 OECD members as well as non-member and developing countries, and were invited to provide a breadth of research, policy, regulation and industry perspectives.

Africa

Overarching science strategies, plans and policies

Mozambique has the best-developed national biotechnology programme, which includes marine biotechnology. Apart from this, Nigeria, South Africa and Tunisia have some elements of biotechnology or marine sciences plans, policies or strategies. Kenya launched a national bioprospecting strategy in 2011 in response to biopiracy.

Research funding schemes and programmes

Tunisia seems most forward in creating a programme that utilizes the relevant expertise of national research institutes.

Research priorities

Biofuels and marine bioactives are the main research priorities. Aquaculture is important but there is not so much evidence of biotechnology applications as part of national programmes (see though Nigeria).

Infrastructures and coordination and support capacities/initiatives

The Mediterranean Science Commission (CIESM), the Inter-Islamic Science and Technology Network on Oceanography (INOC) and the Ocean Data and Information Network of Africa are three notable integrational initiatives with involvement in marine biosciences.

National profiles

Algeria

The General Directorate for Scientific Research and Technological Development DG-RSDT of the Ministry of Higher Education & Research has funded 34 national projects in the period 2008-2012, including some in microbial biotechnology and nanotechnology for renewable energy. However, the major biotechnology effort in Algeria is for human health and the pharmaceutical industry, with involvement of the Ministry of Health, Population and Hospital Reform as well as DG-RSDT.

According to the EU's erawatch service, there are no defined strategies or policies but signs that green chemistry is clustering round Oran, biotechnology in Constantine and sustainable development and energy in Tlemcen http://erawatch.jrc.ec.europa.eu/erawatch/opencms/information/country_pages/dz/country?section=RegionalResearchPolicies&subsection=RegResearchPoliciesAndProgrammes.

The University of Béjaia has recently reported work on antifungal marine extracts, from the Department of plant biotechnology and ethnobotany http://www.academicjournals.org/AJb/abstracts/abs2012/15May/Saidani%20et%20al.htm.

Cameroon

The National Directory of Marine and Freshwater Professionals and Institutions in Cameroon is part of ODINAFRICA and is held at MINREST-IRAD, the Research Station for Fisheries and Oceanography of the Institute of Agricultural Research for Development http://www.nodc-cameroon.org/nadirect.pdf.

The University of Douala is involved in an unspecified aspect of biotechnology http://www.university-directory.eu/Cameroon/University-of-Douala.html.

Egypt

The Biotech International Research & Development (BIRD) Centre is a private centre for consultancy and scientific research in algae and water quality, renewable energy sources and the use of algal biomass for biofuels, bioactive molecules, animal feed and organic fertilizers http://bird.techno-zone.net/tg-who-we-are. Its expertise includes algal ecology, physiology, biochemistry and chemotaxonomy, biotechnology and mass culture; genetic engineering and tissue culture of marine invertebrates, chemistry of natural products, chemistry of phycocolloids, organic chemistry, analytical chemistry, and petrochemistry.

NIOF (the National Institute of Oceanography and Fisheries www.imp-med.eu/En/image.php?id=211), in Alexandria, is developing laboratory culture of micro- and macroalgae containing bioactives, and Red Sea sponge-extracts with activity against hepatitis C virus and cancers (Strategic Goal 2). NIOF is also working on the use of biotechnology for marine monitoring and remediation (Strategic Goal 3).

Mubarak City for Science, Research and Technology Applications is a partner in the EU-funded project ULIXES (using Mediterranean biodiversity for environmental remediation). The Suez Canal University has work on biodiscovery from Red Sea organisms and has been a contributor to EC-US-CIESM meetings on marine biotechnology topics.

Kenya

The Ministry of Forestry and Wildlife and the Kenya Wildlife Service launched a National Bio-prospecting Strategy in November 2011, within the Vision 2030 National Strategy http://www.forestryandwildlife.go.ke/?p=711. This will invest KSh 10B (c. €95M) in infrastructures and training in management and regulation. The marine biodiversity content is unclear, but an example of biopiracy is mentioned involving novel enzymes from micro-organisms in Lake Bogoria.

KIMFRI (the Kenya Marine and Fisheries Research Institute) is a State Corporation under the Ministry of Fisheries Development http://www.kmfri.co.ke/. There is research in natural products from fish and marine invertebrates, and post-harvest technology for fish-processing, though the latter is more dominant.

Nairobi University was a member in the EU-funded project LIPOYEASTS.

Morocco

CNRST (the National Centre for Science and Technology Research) is a contributor to EU-US-CIESM meetings on marine biotechnology topics http://www.cnrst.ma/. Its Laboratory of Microbiology and Molecular Biology hosts the Moroccan Microbial Culture Collection CCMM, which forms the basis of the Moroccan Biological Resources Centre. The University Hassan II in Casablanca is a partner in the EU-funded project ULIXES (using Mediterranean biodiversity for environmental remediation).

Mozambique

Mozambique has a National Biotechnology Programme managed by the Ministry of Science and Technology http://www.mct.gov.mz. There is active interest in sustainable marine biodiversity development. Mozambique is the source of thiocoraline, a thiodepsipeptide first isolated from Micromonospora marina, an actinomycete bacterium collected from coastal waters and developed further by the Spanish marine drug company PharmaMar (http://www.pharmamar.com/en/about/) as an anti-cancer candidate for solid tumours.

Nigeria

A National Biotechnology Policy exists. It was adopted in 2001, leading to establishment of NABDA (the National Biotechnology Development Agency http://www.nabda.gov.ng/) in order to use biotechnology to support Nigeria's social and economic growth. NABDA supports or facilitates mainly agricultural and healthcare biotechnology, including capacity-building, and is the agency involved in biotechnology regulation. Environmental biotechnology aspects include some use of river or brackish sediment organisms for bioremediation and waste conversion. NABDA has 6 zonal (regional) Biotechnology Centres and 8 Bioresources Development Centres.

NIOMR (the Nigerian Institute for Oceanography and Marine Research http://www.niomr.org/) has a Fish technology/biotechnology department that carries out research and provides training in fish genetics and genomes http://www.niomr.org/fishingtech.html.

Sénégal

There is a Centre de Recherches Océanographiques de Dakar Thiaroye, but this focuses on marine fisheries and aquaculture and not on value-added products and marine biotechnology.

South Africa

South Africa published a National Biotechnology Strategy in 2001, which does not however mention marine biotechnology http://www.info.gov.za/view/DownloadFileAction?id=70280. By 2007, 500M ZAR had been spent.

DAFF (the Department of Agriculture, Forestry and Fisheries) is proposing to establish a new programme on aquatic biological research, though this has a strong focus on aquaculture and stock improvement[11]. The Department of Environmental Affairs has an Oceans and Coasts branch http://www.environment.gov.za/?q=content/branches/oceans_coast, which is developing an interest in marine biotechnology. SANCOR (the South African Network for Coastal and Oceanic Research http://sancor.nrf.ac.za/sancor-forum-2012) has established a national funding programme for marine-related research and DAFF, DEA and SANCOR collaborate in a coastal province programme, involving Eastern Cape, KwaZulu-Natal and Northern Cape.

The University of the Western Cape's IMBM (Institute for Microbial Biotechnology and Metagenomics http://imbm.co.za/) has activity in genomics of Antarctic, shallow marine and thermophilic microbes and is a partner in the EU-funded project PharmaSea. UWC and the DEA's Oceans and Coasts have recently signed a Memorandum of Understanding and there is a prospect of a Center of Excellence in marine biotechnology being established at UWC.

[11] See http://sancor.nrf.ac.za/reports/DAFF%20RESEARCH%20PERSPECTIVE.pptx

Tunisia

A member of CIESM and the subject of a recent report "*Blue biotechnology potential in Tunisia - a preliminary study of national stakeholders' involvement in setting priorities*"[12], Tunisia has been quite active since 1975 in marine biosciences and biotechnology.

The Tenth Economic and Social Plan 2002-2006 established 'techno-poles' including one intended as a marine technologies network. Between 2004 and 2009, the Government established Instituts Supérieures de Biotechnologie, of which the one in Monastir includes marine biotechnology in its programme of work and education http://www.isbm.rnu.tn/francais/Acceuil.htm.

INSTM (the National Institute of Marine Sciences & Technologies http://www.instm.agrinet.tn/an/accueil.php) has worked since 1999 on marine biotechnology at 5 of its institutes: La Goulette (the most important): biotransformation of marine wastes and bioenergy; Khéreiddine: macro-algal biotechnology and bioactive products; Carthage: pharma and health, fisheries and aquaculture; and Monastir: thermophilic microalgae and bioproduction.

There are other institutions with partial MB interests, including INSAT (the National Institute of Sciences and Technology http://www.insat.rnu.tn/Fr/laboratoires-et-unites-de-recherche_11_7): thermotolerant microorganisms; University of Tunis El Manar http://www.utm.rnu.tn/ensite/index.php?pg=126&id_etab=3: bioactive compounds in sponges and halophilic cyanobacteria; and the Center of Biotechnology of University of Sfax http://www.isbs.rnu.tn/: microalgae, valorisation of marine bioresources.

[12] Onofri L and Briand F (2012) – see http://www.ciesm.org/Tunisia_report.pdf

Americas

Central & South America

Overarching science strategies, plans and policies

Brazil and Chile have national biotechnology plans. Chile also has a national Innovation Plan (2012-2014). Argentina's Law 26270 focuses on building the economy through facilitating biotechnology enterprise. Mexico has PECiTI (the national Science, Technology & Innovation programme), and a National Development Plan 2007-2012. No country has a marine biotechnology strategy, but Brazil carries out strategic R&D through a specific programme BIOMAR, established in 2005, and Costa Rica has an institute to manage the exploration and use of biodiversity, INBio, established in 1989.

Research funding schemes and programmes

National schemes and programmes, with the exception of Brazil's BIOMAR, are generic, though many of them do support marine biotechnology. BIOMAR began road-mapping marine biotechnology in Brazil in 2007. It is a good case study for national marine biotechnology support programmes. Marine biodiscovery is recognized in Costa Rica's Bioprospecting programme (1991).

Research priorities

The focus is very broad, including biodiscovery, bioenergy, bioremediation and biofouling. In Chile, there is also activity in molecular aquaculture, because of the importance of this sector to the economy. There are numerous universities and research centres involved in marine biotechnology in Brazil, Chile and Mexico.

Infrastructures and coordination and support capacities/initiatives

The best examples of academic infrastructure and support are to be found in Brazil, the government-funded networks RedeAlgas (macroalgae), Rede interinstitucional de algas bentônicas (microalgae) and Rede Brasileira de Tecnologia de Biodiesel (biodiesel).

The Mesoamerican Reef Alliance and the Mesoamerican Barrier Reef System Project brought countries in Central America together to help reduce human damage to the reefs and encourage sustainable use. The Mesoamerican Barrier Reef System runs from Yucatán in Mexico down to Honduras, and includes Belize, Guatemala, Nicaragua and northern Costa Rica in the associated waters. The project ended 2007.

National profiles

Argentina

National strategy for biotechnology

There is no formulated biotechnology strategy as such. Law 26270 was passed in July 2007 by the Congress of Argentina for the Promotion of Development and Production of Modern Biotechnology Benefits from Research Projects (http://www.infoleg.gov.ar/infolegInternet/verNorma.do?id=130522).

It created a Stimulus Fund for new ventures in biotechnology, offering incentives on biotech R&D such as accelerated depreciation on capital items, early VAT reimbursement, tax relief on listed property and fiscal credit on social security contributions and purchases of R&D services from government institutions.

National strategy for marine biotechnology

There is no national strategy for marine biotechnology

Programmes

National R&D and innovation funding programmes are generic towards business-improving developments. They include FONTAR – Argentine Technology Fund, FONCYT – the Scientific and Technology Research Fund, managed by the National Agency of Science & Technology Promotion MINCyT. MINCyT also sets out the quota of R&D tax credits. Interactions and coordination between the Argentine states are encouraged through the Federal Science and Technology Council COFECYT.

Centres of marine biotechnology research

Research priorities seem mainly focused on Bioprospecting.

INGEBI (the Research Institute for Genetic Engineering and Molecular Biology), in Buenos Aires, has extensive industrial links and also collaborates with CNRS in France http://www.ingebi-conicet.gov.ar/el_ingebi.php.
CONICET-CENPAT, (the Centro Nacional Patagónico) has research on marine microbes and industrial use, including bioprospecting for new medicines http://www.cenpat.edu.ar/.
The Universidad Nacional de la Plata was a partner in the EU-funded project METAEXPLORE.

Infrastructures and coordination and support capacities/initiatives

More information is needed.

Brazil

Brazil is an important country for marine biotechnology research and development. A recent report[13] identified over 500 groups potentially active across the areas comprising marine biotechnology interest, directly active in marine biotechnology or supporting it through biology, ecology, molecular biology etc.

Brazil is recognised as an International Cooperation Partner Country, so that Brazilian institutions can be involved in appropriate EU-funded projects; there are also specific marine sciences bilateral collaboration agreements with Germany and France.

National strategy for biotechnology

The most recent national biotechnology development strategy was formulated in 2007.

National strategy for marine biotechnology

There is no marine biotechnology strategy as such, but the strategic developments in this sector are accomplished through the BIOMAR programme. At Federal level, the Ministry of Science, Technology and Innovation (MCT) established BIOMAR (Programa de Levantamento e Avaliaçao do Potencial Biotecnológico da Biodiversidade Marinha) in 2005 https://www.mar.mil.br/secirm/i-biomar.htm. The BIOMAR Executive Committee includes representatives of 6 Ministries, 4 organisations and one commercial organization (Petrobras - Empresa Petróleo Brasileiro S/A).

[13] www.mct.gov.br/upd_blob/0214/214212.pdf Laneuville Teixeira, V (2010) *Caracterização do Estado da Arte em Biotecnologia Marinha no Brasil* Ministério da Saúde. Organizaçao Pan-Americana da Saúde. Ministério da Ciencia e Tecnologia. Brasilia, Brazil.

Programmes

The BIOMAR Executive Committee established a proposal for a national work activity and in 2007 began the process of mapping research capacity and achievements in marine biotechnology in Brazil. Funding calls within the BIOMAR strategic programme are managed by CNPq (the National Council for Scientific and Technological Development) with additional support from MCT, resulting in a first call for biodiesel projects in 2008 and another for more general marine biotechnology research in 2009, together over 30 projects. Further calls have followed. CIRM (Comissão Interministerial para os Recursos do Mar https://www.mar.mil.br/secirm/i-index.html) is also involved in supporting aspects of marine biotechnology, including the report on its status in Brazil, and works through SEPED (the Secretariat for Research and Development Policies and Programmes), for research in the Antarctic http://www.mct.gov.br/index.php/content/view/6961.html.

Individual states also have R&D funding and Innovation funding programmes.

Centres of marine biotechnology research

UFRJ (Universidade Federal do Rio de Janeiro – 35 groups) http://www.ufrj.br/
UFC (Universidade Federal do Ceará – 23 groups) http://www.ufc.br/
USP (Universidade de São Paulo – 20 groups) http://www5.usp.br/en/
UFSC (Universidade Federal de Santa Catarina – 20 groups) http://ufsc.br
UEC (Universidade Estaduale de Campinas – 19 groups) http://www.unicamp.br/unicamp/?language=en and a partner in the EU-funded project BAMMBO
UFPE (Universidade Federal do Pernambuco – 16 groups) http://www.ufpe.br/english/
UFF (Universidade Federal Fluminense – 15 groups) http://www.uff.br/: a Marine Biotechnology group in the Marine Biology Department working on bioactives, for example novel anti-HIV molecules from algae; the Marine Microbiology laboratory working on oil-pollution remediation; and research in the Dept of Cellular and Molecular Biology; UFF and IEAPM (Instituto de Estudos do Mar Almirante Paulo Moreira http://www.ieapm.mar.mil.br/) collaborate on natural anti-foulants (biofilm inhibitors).
FURG (Fundação Universidade Federal do Rio Grande – 14 groups) has activity in bioactives from marine invertebrates and in biotechnology and processing of seafood, including value-added products http://www.furg.br/. Ciências do Mar Brasil (http://www.cdmb.furg.br/) is based at FURG.
UFBA (Universidade Federal da Bahia – 13 groups) https://www.ufba.br/
UFPR (Universidade Federal do Paraná – 11 groups) http://www.ufpr.br/portalufpr/
UERJ (Universidade do Estado do Rio de Janeiro)
UFPA (Universidade Federal do Pará) http://www.portal.ufpa.br/
UFSCAR (Universidade Federal do São Carlos) http://www2.ufscar.br/english/index.php: work on molecular aquaculture of shrimp, mapping the genome for molecular markers of productivity and disease resistance.
CEM (Centro de Estudos do Mar) is involved in the microbiology and chemistry of phytoplankton, zooplankton and invertebrates http://www.cem.ufpr.br/.

Infrastructure

The Brazilian government strongly supports networks. There are three highly relevant for marine biotechnology, including:
RedeAlgas (the National Network on Macroalgae Biotechnology), established in 2005 by joint funding between MCTI and CNPq http://redealgas.ibict.br/. It has held 3 conferences on the biotechnological potential of seaweeds, bioactives and making sustainable use of macroalgal biodiversity. The network includes the most active research groups in over 20 universities.
Rede interinstitucional de algas bentônicas, an inter-University collaboration working on algal bioactives for pain, inflammation and other conditions, involving the Federal Universities of Alagoas, Rio Grande do Norte, Pernambuco and Paraíba. This received R$730,000 from MCTI, CNPq and DECIT for set-up and initial projects.
RBTB (Brazilian Biodiesel Technology Network is funded by MCT within the National Program for Production and Use of Biodiesel), part of the activities of the Ministry of Mining and Energy

http://www.mme.gov.br/programas/biodiesel/menu/rede_brasileira_tecnologia/sobre_a_rede. RBTB was set up in 2004 with funds of R$ 12M. It includes universities such as UFG and UFPR.

SEPED/MCT funds PPBIO, a Biodiversity Research Program, established in 2006 (www.cgee.org.br/atividades/redirect.php?idProduto=2945), which produced a report on strategies for modernising Brazil's culture collections and integrating biodiversity information www.anbio.org.br/pdf/2/diretrizes.pdf.

Private investment

The Austrian company SAT (See Algae Technology) is building an algal technology pilot plant at a cost of almost $US 10M, in collaboration with Grupo JB, a sugarcane ethanol production plant in Pernambuco state, to produce biofuels, algal biomass for animal feed, and extractable chemicals and lipids http://www.prnewswire.com/news-releases/see-algae-technology-gmbh-announces-sale-of-algae-farm-to-brazils-grupo-jb-159566075.html. The target is to produce 1.2M litres of biofuels, using the CO_2 output of the ethanol plant for algae growth, beginning with a 1 Ha test plant in late 2013. GM and non-GM microalgae will be used.

Chile

National strategy for biotechnology

The national strategy for biotechnology development was launched in 2003.

CNIC (the National Council for Innovation for Competitiveness) was set up in 2005 and produced a national strategy, amongst other tasks, which identified cluster development and economy-led science as targets, and the National Innovation Agenda for Competitiveness 2010-2020. The Agenda established Biotechnology, Energy, Environment and Food, agriculture & fisheries as key strategic areas (select Chile at http://erawatch.jrc.ec.europa.eu/erawatch/opencms/information/country_pages/)

Biotechnology R&D support is set in the context of national innovation plans, the most recent being the 'Innovation Plan to 2014 – Chile: Innovation Pole of Latin America' (2012). The Ministry of Education's National Commission for Science and Technology Research CONICYT, the national Research Fund for Science and Technology FONDECYT and the Ministry of Economy's Economic Development Agency CORFO provide funding for biotechnology R&D, innovation and company activities.

National strategy for marine biotechnology

There is no national strategy for marine biotechnology.

Programmes

FONDEF (Fondo del Fomento al Desarrollo Científico y Tecnológico http://www.fondef.cl/content/view/111/73/) supports work in algal biofuels.
Chile's economic development agency CORFO (Corporación de Fomento de la Producción http://www.corfo.cl/) is also involved in some work supporting utilisation of marine bioresources (eg the seaweed project at UCN and the algal Biorefinery project involving the US company BAL).

Centres of marine biotechnology research

These include:
CASEB (the Center for Advanced Studies in Ecology & Biodiversity http://www.casebchile.cl/) at the Pontificia Universidad Católica de Chile;
CIByB (the Center for Academic Excellence in Biochemical Engineering and Biotechnology http://www.cibyb.uchile.cl/Cibyb.htm) at the Universidad de Chile, working on marine organisms, their genes and enzymes as research tools and as sources of industrially-useful molecules such as low-

temperature enzymes from Antarctic krill, and metabolic flux in ethanologenic yeasts for seaweed digestion;
CIDTA-UCN (the Research and Technological Center in Applied Phycology http://www.cidta-ucn.cl/investigacion_eng.html) at the Universidad Católica del Norte, a purpose-built centre for new macroalgal developments for the food, agriculture, pharmaceuticals and cosmetics industries, including bioactives from seaweeds. It was funded jointly by CORFO (600M pesos in 2007), UCN and seaweed companies. UCN is also a partner in the EU-funded project MAREX;
ICDB (Institute for Cell Dynamics and Biotechnology http://www.icdb.cl/componentes_english.html), Santiago, a partner if the FP7 project PharmaSea, with isolates from Antarctica and the Atacama trench activities in genomic metabolic engineering of all main marine organisms including *Salinospora*;
UANTOF (Universidad de Antofagasta http://www.uantof.cl/), a partner in the EU-funded projects MAMBA, and MARINE FUNGI (https://www.marinefungi.eu/) coordinated by GEOMAR Germany, aiming to isolate new anticancer drugs from marine fungi;
UDEC (Universidad de Concepción http://copas.udec.cl/eng/) has an active group investigating photosynthetic organisms including microalgae and marine and freshwater diatoms, toxic algae, and bioactives such as pigments. UDEC's Centro de Biotecnología is highly involved in algal projects, including 'Biotecnología en algas' aimed at local schoolchildren; macro-and microalgal bioenergy (FONDEF provided 565M pesos in 2009-2011) http://www.centrobiotecnologia.cl/index.php/areas/biocombustibles/biodiesel-de-microalgas; UDEC's molecular aquaculture group works on microalgae, investigating pigments and use of algae as aquaculture feeds, applying genetic improvement through mutagenesis and selection and -omics to identify microalgal strains with biotechnology applications http://www.centrobiotecnologia.cl/index.php/areas/acuicola/microalgas; and the Environmental Microbiology group researches biofouling.

Private investment

Bio Architecture Lab, a US company, began to build a seaweed biofuel plant in December 2011 in the Los Lagos area of Chile. The plant will use *Macrocystis pyrifera* as feedstock. Its Chilean subsidiaries, BALChile and BALBioFuelsChile, are collaborating with the Universidad de Los Lagos, and the ICDB and CiBYB, and are supported by CORFO. BAL already had 3 seaweed farming sites in Chile.

Colombia

There is no biotechnology strategy as such, or marine biotechnology strategy. Colombia has established a biotechnology-promoting programme of R&D centres, economic support and fiscal incentives to encourage biotechnology-based innovations and is undertaking a number of international collaborations for knowledge and technology transfer to build its capacities (eg with Purdue University USA https://engineering.purdue.edu/EngineeringImpact/2011_1/purdue-colombia-forge-strategic-partnership, and the FEMSA Foundation of Tecnológico de Monterrey Mexico http://www.femsafoundation.org.

INVEMAR (Instituto de Investigaciones Marinas y Costeras http://www.invemar.org.co/ingles/index.jsp) has a programme on marine biodiversity, as well as relevant activities in biodiversity, ecology and mariculture.

The private company CorpoGen is a partner in the FP7 EU-funded project MAGICPAH. The company is involved in metagenomic analyses of Colombian biodiversity, including the microbes associated with marine sponges http://www.corpogen.org/web/investigacion.html#Lineas.

Costa Rica

Costa Rica's Biodiversity Law was enacted in 1988, leading to the setting-up of CONAGEBIO (the National Commission for Biodiversity Management), bringing together government departments and interest bodies including trade associations. The law also set up access and benefit-sharing (ABS) requirements, including up-front payments of up to 10% from research budgets, when possible, to support conservation, and up to 50% share of royalties.

The Costa Rican Government launched a national 'Políticas Azules', Blue Agenda, in November 2012, under the leadership of a newly-created post of Deputy Minister of Water and Seas. The new Minister, Alfio Piva, emphasized the need for a national policy on sustainable development for coastal marine areas, increased surveillance of marine resource extraction and termination of pollution of coasts and gulfs http://lafraguacr.org/2012/11/05/gobierno-lanzo-hoy-politicas-azules-y-nuevo-viceministerio-de-agua-y-mares/.

Costa Rica's National Biodiversity Institute INBio (http://www.inbio.ac.cr/en/) was founded in 1989, one year after the Biodiversity Law was enacted. It is a non-government private organisation. Its Bioprospecting Programme was established in 1991, and marine biodiversity exploration began in 1995. INBio has worked under the Biodiversity Law's ABS scheme since its foundation and has also been involved in capacity-building and technology transfer activities through collaborations with commercial and academic partners.

Collaborations on marine biodiversity include evaluation of the potential applications of marine sponge bioactives in collaboration with INVEMAR (Colombia) and the Henry Ford Hospital (USA), since 2003; screening of natural products from marine macro- and microorganisms in an ICBG (International Cooperative Biodiversity Groups) project with Harvard Medical School and University of Michigan, targeting CNS, antiparasite and anticancer activities; and novel antimicrobials from unexplored sources, such as crustacean and insect gut flora, with CNB (Centro Nacional de Biotecnología, Spain). INBio has also worked with the US company Verenium on unculturable microorganisms for the development of industrial enzymes, leading to commercialisation of a new green fluorescent marine-based protein, and is a partner in an FP7 EU-funded project, PharmaSea. The Ministry of Foreign Trade, the Costa Rican Investment Promotion Agency CINDE and the Spanish company PharmaMar announced in October 2012 a funded cooperation agreement between PharmaMar and INBio, exploring Costa Rican marine organisms for new anti-cancer agents http://www.cinde.org/en/news/18-news/306-important-biotechnology-research-project-to-fight-cancer-taking-place-in-costa-rica.

National universities are also involved in marine biodiversity and pollution studies, mainly CIMAR (Centro de Investigación en Ciencias del Mar y Limnología http://www.cimar.ucr.ac.cr/) at the University of Costa Rica UCR and the National University (UNA). In 2011, UCR started activities in microbial ecology, through a postgraduate course funded by the Spanish Agency for International Cooperation for Development (AECID) http://www.ucr.ac.cr/noticias/2011/07/20/ucr-abre-nueva-linea-de-investigacion-marina/imprimir.html.

Mexico

National strategy for biotechnology

There is no specific biotechnology strategy.
Mexico has a national programme, PECYT, the Special Programme for Science and Technology 2001-2006 and PECiTI, the Special Programme for Science, Technology and Innovation 2008-2012 (http://ebookbrowse.com/gdoc.php?id=22949787&url=1216324f5c00590612ec96aca8c54aa3), and a National Development Plan 2007-2012. PECiTI puts biotechnology at the top of a list of technology

priorities for use in national development but the only theme in which biotechnology is a focus is that of biosecurity and biotechnology.

National strategy for marine biotechnology

There is no national strategy for marine biotechnology.

Programmes

Mexico's CONACYT (National Council of Science and Technology) is responsible for a number of publicly-funded research centres throughout the country and for the scope of National Programmes and Development Plans.

Centres of marine biotechnology research

CICESE (the Centro de Investigación Científica y de Educación Superior de Ensenada http://www.cicese.edu.mx/int/index.php?mod=acd&op=intro) is a state-funded institute. CICESE's Department of Marine Biotechnology researches ecology, biochemistry and molecular genetics of marine biodiversity, with applications in marine natural products, biotechnology in aquaculture, bioremediation, bioprocess engineering, biomass biorefinery and functional nutrition http://www.cicese.edu.mx/int/index.php?mod=inv&op=ac&dep=6802.

The National Autonomous University of Mexico has several marine biotechnology activities, including the Dept of Ecology and Aquatic Biodiversity (http://www.icmyl.unam.mx/?q=node/17), the Mazatlán Research Dept on the Pacific Coast (http://www.icmyl.unam.mx/?q=node/19) the Reef Systems Unit at Puerto Morelos (http://www.icmyl.unam.mx/arrecifes/rsu.html) and the Unit of Oceanic and Coastal Processes, which together form ICMYL, the Instituto de Ciencias del Mar y Limnología (Institute of Marine Science and Limnology http://www.icmyl.unam.mx/?q=node/6.

The Biological Oceanography group at the Oceanology Institute, Autonomous University of Baja California, is active in molecular aquaculture for shellfish and crustacea and advanced cultivation methods for seaweeds http://iio.ens.uabc.mx/servicios/servicioarea.php?area=1.

Universidad del Mar (UMAR) maintains a culture collection in the Institute of Resources (http://www.umar.mx/investigacion.html#ir). Its Institutes and groups in Genetics, Biotechnology, Marine Biology, Environmental Biotechnology and others based at Puerto Ángel have relevant marine biotechnology activities.

The Unidad Mérida of CINVESTAV (Centro de Investigación y de Estudios Avanzados http://www.mda.cinvestav.mx/) has an Aquaculture, Fisheries and Biotechnology programme within the Ocean Resources department. A current project is assessment of bioactive molecules in seaweed of the Yucatán coast, funded by CONACYT and SEP, the Education Secretariat.

North America

Overarching science strategies, plans and policies

Canada published its first National biotechnology strategy in 1983 and renewed it in 1998. Genome Canada was founded in 2000 as 'a catalyst for developing and applying genomic sciences that create economic wealth and social benefit'. The USA announced in 2011 a National Bioeconomy Blueprint. Neither country has a specific marine biotechnology strategy, plan or policy. The Canadian marine strategy of 2002 and Healthy Oceans Initiative of 2007 contain some elements that might be relevant but the overall focus is on sustainability and integrated approaches to oceans.

Research funding schemes and programmes

Fisheries and Oceans Canada has a strong programme in aquatic biotechnology and genomics and the National Research Council supports the Institute for Marine Biosciences in Nova Scotia. Genome Canada, through its regional activity in British Columbia, is a partner in the international Salmon Genome project and has other fisheries and environmental activities that are relevant for marine biotechnology. Québec supports the Marine Biotechnology Research Centre in Rimouski, which is an industry-facing development organization. In the USA, the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the Department of Energy and Department of Defense support aspects of marine biotechnology, the last 2 focusing strongly on algal biofuels. NSF was the main supporter of the enormous Microbial Observatories programme, and NOAA has 3 relevant programmes, national Sea Grant, Ocean Explorer and National Undersea Research.

Research priorities

Although there is effort on biodiscovery and other aspects of marine biotechnology, including molecular aquaculture in Canada (salmon) and Atlantic Coast of USA (shellfish), the picture is heavily skewed by Dept of Energy and Dept of Defense support for algal biofuels, and private investment in algal biorefineries. There are individual units and centres with a strong marine biotechnology focus (Harbor Branch, Scripps, Bigelow and Maryland spring to mind). Most recently, the state of North Carolina has established a Marine Biotechnology Center of Innovation as part of its economic development plan.

Infrastructures and coordination and support capacities/initiatives

There are some regional initiatives (ArcticNet in Canada, GulfBase in the USA for example) but the most important US-stimulated contribution to international support for marine biotechnology has been the Census of Marine Life (CoML). Canada is also involved in the OECD marine biotechnology initiative.

National profiles

Canada

In 2009, according to Canadian Government statistics, 208 firms reported revenues from bioproducts amounting to C$1.3 billion (of which over C$900M came from bioethanol) http://www.statcan.gc.ca/daily-quotidien/110224/dq110224f-eng.htm. 5% of the companies obtained their biomass from marine and aquaculture sources.

National strategy for biotechnology

Canada's first National Strategy was published in 1983 and renewed in 1998. It dwells more on biosafety and regulation than on scientific or economic development programmes.

A review of key biotechnology strengths in 2005[14] noted that Canada ranked 2nd in the world for scientific publications and impacts in aquatic biotechnology, especially aquaculture, molecular ecology, and environmental monitoring.

National strategy for marine biotechnology

There is no specific marine biotechnology strategy. The 2002 marine strategy and the 2007 Healthy Oceans Initiative contain elements of marine bioscience, biology and bioresource use. Canada has made C$60M available over 5 years for marine activities in the HOI.

Individual provinces have established strategies or action plans for marine biotechnology and bioresource development. Québec has established Project ACCORD (Action concertée de cooperation régionale du développement http://www.mdeie.gouv.qc.ca/objectifs/informer/projet-accord/) including action plans for Niches of Excellence, one of which concerns Marine resources, sciences and technologies, with clusters in marine biotechnology, aquaculture, seafood processing and marine technologies.

Programmes

Fisheries and Oceans Canada (DFO) has a strong R&D programme in Aquatic Biotechnology and Genomics covering resource profiling, aquatic animal health, and ecosystem health http://www.dfo-mpo.gc.ca/science/biotech/abgrds-srdbfa/themes-eng.htm. DFO supports a number of centres of expertise, including CECSSR (coldwater coral and sponge reefs) in St John's Newfoundland http://www.dfo-mpo.gc.ca/science/coe-cde/ceccsr-cerceef/index-eng.asp and CAAHRD (animal health and diagnostics) in Moncton New Brunswick.

The National Bioproducts Program was a joint initiative of the National Research Council of Canada (NRC), Agriculture and Agrifood Canada and Natural Resources Canada. A highly-relevant programme looked at capacity-building for Canadian algal biofuels, involving teams from across NRC (spanning marine biosciences, aerospace research, chemical processing, and biotechnology) http://archive.nrc-cnrc.gc.ca/eng/projects/nbp/biofuels.html.

The National Research Council (NRC) of Canada, a Government Agency, is responsible for over 20 institutes and a number of national programme, some including projects relevant to marine biotechnology, including microalgal bioactives and biofuels, bioprospecting, metabolomics, algal biotoxins and biomedical uses of marine natural products. It provides clients and partners with access to innovation support, strategic research and technical services, with a strong focus on meeting Canada's

[14] Campbell D, Côté G, Bergeron S and Archambault E (2005) *Canadian Biotechnology: Scan of Canadian Strengths in Biotechnology*. Science-Metrix www.science-metrix.com

current and future industrial and societal needs. Apart from its aquatic research activities, NRC undertakes marine research without a direct bio connection, involving chemists, physicists, metrologists, engineers and technicians from across a range of disciplines to help solve complex research and technology challenges.

Genome Canada, a national organisation established in 2000 , linked to independent, regional Genome Centres, is responsible for a national strategy aimed at fostering genomics developments in terms of scientific output, infrastructure support and research talent http://www.genomecanada.ca/. The Genome Canada Enterprise provides support for national and international collaborations in key sectors of importance to Canada.

Within the field of marine biotechnology, Genome Canada and the regional Genome Centres support a variety of genomic applications including molecular aquaculture, metagenomics, and high throughput screening. In partnership with Genome British Columbia, a Canadian-led international collaboration was funded to develop genomic resources for salmonids that are now being used to examine responses to environmental factors, pathogens and pollutants, and for broodstock development. Building on this investment, Genome British Columbia is also partner in the international salmon genome project http://www.genomebc.ca/partners/international-collaborators/international-cooperation-to-sequence-the-atlantic-salmon-geno/ that will provide the knowledge and tools for improved management of wild fish stocks, for selective breeding for the aquaculture industry and for food quality, security and traceability.

Genome Canada and Genome Atlantic have established a public-private-partnership to provide tools and resources to the Atlantic cod aquaculture industry to identify markers for traits related to growth, disease resistance and stress tolerance for marker assisted selection.

Genome Canada and the Ontario Genomics Institute are funding an international initiative called the Barcode of Life (iBOL), part of which deals with marine lifeforms. This technology is now being applied to regulating the labelling of fish in markets and restaurants in several countries .

Genome Canada, Genome Atlantic and Genome British Columbia are also partners in the Organization for Economic Co-operation and Development's (OECD) activities on marine biotechnology.

Centres of marine biotechnology research

The Marine Biotechnology Research Centre in Rimouski, Québec, established in 2004 at a cost of US$14M, is focused on translational research and product and process development for specific industrial needs, via project work for Canadian and international companies http://www.crbm-mbrc.com/index.php. It can call on the scientific, nutritional and medical expertise of a number of local, regional and national partners and also collaborates with the Centre québecois de valorisation des biotechnologies and Merinov, the Centre d'innovation de l'aquaculture et des pêches du Québec, in the Consortium BioMar Innovation. International collaborators include Ifremer, France and Norut's Department of Biotechnology and Barendts BioCentre, Norway. It has GMP-accredited manufacturing facilities and a small business incubator.

Other centres include:
Bedford Institute of Oceanography, which carries out work on ecosystems and ocean behaviour to assist fisheries, aquaculture and ocean resource development http://www.bio.gc.ca/index-eng.php. It operates the Real-Time Arctic Ocean Observatory http://www.bio.gc.ca/science/newtech-technouvelles/observatory-observatoire-eng.php;
Dalhousie University, with a Marine Biology department with some activity in molecular marine studies http://marine.biology.dal.ca/index.php;
McGill University Department of Natural Resource Sciences, which is active in Arctic marine biotechnology, both bioprospecting and bioremediation of pollution http://www.mcgill.ca/nrs/;

The Ocean Sciences Centre, Memorial University of Newfoundland, which includes molecular biology, molecular aquaculture and biological oceanography in its activities http://www.mun.ca/osc/research/;
The University of Prince Edward Island, collaborating with Nautilus Biosciences Canada as part of Nautilus's biodiscovery activities http://news.upei.ca/media/2010/08/23/upei-licenses-new-technology-pei-bioscience-company;
The University of Toronto, a participant in EU-funded projects MAGICPAH and MAMBA.

Private investment

Leading companies using marine bioresources include Ocean Nutrition Canada Limited, the world's largest supplier of Omega-3 EPA/DHA ingredients to the dietary supplement and food manufacturing markets, recently purchased by Royal DSM; Acadian Seaplants Ltd, which processes seaweed into products for food, biochemical, agricultural and agri-chemical markets; Jellett Rapid Testing, with screening tests to identify paralytic shellfish poisoning; Kenney & Ross Ltd, the world's largest manufacturer of fish gelatine products, which uses seafood by-products as the source of an anti-inflammatory for the pet market; and Nautilus Biosciences Canada Inc., which is focused on the discovery and sustainable development of marine-derived natural products with applications in human and animal health and wellbeing.

Infrastructures

These include:
ArcticNet, a network of centres of excellence working on the impacts of climate change and modernisation in the Arctic North of Canada, including ecosystems, Inuit adaptation and industrial development http://www.arcticnet.ulaval.ca/. ArcticNet involves 30 Canadian Universities, 19 Federal and Provincial agencies and research teams from 12 other countries (Denmark, Finland, France, Greenland, Norway, Poland, Russia, Spain, Sweden, UK; Japan; USA). It has received start-up funding of C$140M;
CCCM (the Canadian Center for the Culture of Microorganisms http://www3.botany.ubc.ca/cccm/), which hosts NEPCC (the North East Pacific Culture Collection) and FWAC (the Freshwater Algal Culture Collection);
NSERC's Canadian Healthy Ocean Network, a Strategic Research network studying marine biodiversity http://chone.marinebiodiversity.ca/.

DAMAMNet (Discovery and Application of Marine Active Materials network) was a short-lived project intending to link the Maritime Provinces (New Brunswick, Newfoundland/Labrador, Nova Scotia and Prince Edward Island) with Quebec, in a number of research projects in marine bioactives, adding value to underused marine catches and fisheries by-products, commercialisation of marine algae, new biopolymers and new processing and separation technologies.

The ONC (OCEAN NETWORKS Canada) Observatory, off the NE Pacific coast of British Columbia, is managed by the University of Victoria. It is currently the world's most important regional ocean observatory facility, linking remote sensors and instrumentation by cable with the Internet to allow an extremely broad range of physical, chemical, biological and geological variables to be continuously and simultaneously measured http://www.oceannetworks.ca/onc-observatory. The ONC Observatory is an unparalleled tool for ocean experiments on the seafloor and through the water column, including studies of marine genomics of hydrothermal vent systems and other subsea environments.

United States of America

National strategy for biotechnology

In September 2011, President Obama announced a National Bioeconomy Blueprint detailing Administration-wide steps to harness biological research innovations and address national challenges in health, food, energy, and the environment. The Blueprint was released April 2012 http://www.whitehouse.gov/blog/2012/04/26/national-bioeconomy-blueprint-released.

National strategy for marine biotechnology

There is no nationally coordinated strategy for marine biotechnology in the USA. Although marine biotechnology is not mentioned specifically in the National Bioeconomy Blueprint, biodiesel from algae and biosensor for marine pollution are used as examples of US innovation and conservation and management of marine resources are described as 'critically important to a bioeconomy'. Marine biotechnology was mentioned in a National Science Council report in 1995[15].

Programmes

The NSF (National Science Foundation http://www.nsf.gov/bio/about.jsp) is an independent federal agency created by Congress in 1950, with an annual budget of about $6.9 billion (FY 2010). It funds c. 20% of all publicly-funded academic basic research in all non-medical fields. BIO (the Directorate for Biological Sciences) managed the Microbiology Observatories (MO) and Microbial Interactions and Processes (MIP) programmes, which included significant elements of marine ecology, microbiology and biotechnology. BIO's total funding for 2011 and 2012 is approximately $712M, rising to $733M in 2013. The NSF is a contributor to EC-US Task Force meetings on marine biotechnology topics.

The USA's NOAA (National Oceanic and Atmospheric Administration http://www.research.noaa.gov/oceans/t_biotech.html) coordinates most of the applied marine biotechnology research in USA. Research is supported through the National Sea Grant College Program http://www.research.noaa.gov/programs/seagrant.html, currently as part of the national plan '*Meeting the Challenge, 2009-2013*' www.seagrant.noaa.gov/other/admininfo/documents/0209_stratplan.pdf. The Program consists of 32 university-based networked programmes, including coastal, oceanic (http://oceanexplorer.noaa.gov/) and undersea (http://www.nurp.noaa.gov/Biotech.htm) work, across the entire USA. The Ocean Explorer program manages a research boat and provides a broad range of oceanic data in addition to bioresources exploration. The National Undersea Research Program includes biodiscovery, bioactives, and an active organism repository with over 2000 compounds available for screening based at the University of Mississippi.

The Sea Grant Program had a total budget of $62 million in 2011 and the budget is expected to increase to c. $70M in 2013. *Meeting the Challenge* mentions cutting-edge and new technologies, but does not mention marine or any other biotechnology specifically. NOAA's Northwest Fisheries Science Center and Center for Coastal Environmental Health and Biomolecular Research are contributors to EC-US Task Force meetings on marine biotechnology topics.

DOE, the Department of Energy, is supporting marine biotechnology and especially the production of bioenergy from algae[16], through the ARPA-E agency (Advanced Research Projects Agency-Energy). Over 30 algal-based projects have been supported, at a cost of $85M. In February 2012, the US Government announced a new $14M programme for development of algal biofuels, which is intended to help USA reach its Biomass Program's goal of >1B US gallons of algal-origin biofuels by 2022. The new programme is aimed at small businesses, in collaboration with academic units and national laboratories and may be extended in 2013 by a further $7M.

Centres of marine biotechnology research

California	Scripps Institution of Oceanography CMBB, UC San Diego	CMBB (Center for Marine Biotechnology and Biomedicine) has a strong programme in marine biodiscovery, with spin-out Nereus Pharmaceuticals assisting in commercialisation of some of the outcomes and collaboration with UCSD's School of Pharmacy. The Scripps is a contributor to EC-US Task Force meetings on marine biotechnology topics http://cmbb.ucsd.edu/.
	California Institute of	Caltech is a contributor to EC-US Task Force meetings on marine biotechnology topics. It hosts the Sea Urchin genome database SpBase

15 *Biotechnology for the 21st Century: New Horizons*. NRC 1995

16 See http://arpa-e.energy.gov/ProgramsProjects/OtherProjects/BiomassEnergy.aspx for examples

	Technology	(http://www.spbase.org/SpBase/index.php) and has recently succeeded in producing a bioartificial jellyfish http://www.sciencedaily.com/releases/2012/07/120722135156.htm.
Colorado	Colorado State University	CSU has some work on algae for biofuels, including modelling and processing systems
Delaware	The University of Delaware	UD is a contributor to EC-US Task Force meetings on marine biotechnology topics
Florida	HBOI, Florida Atlantic University	HBOI (the Harbor Branch Institute) hosts CMBBR, the Center for Marine Biomedical and Biotechnology Research CMBBR is involved in drug discovery and characterization, marine biofuels and green chemistry http://www.fau.edu/hboi/.
	The Smithsonian Institute's Marine Station	SI collaborates with Australia's Taronga Zoo on cryopreservation of sponge polyps, operates a network of marine stations from the Caribbean through Central America along the USA's western seaboard, and has carried out work on bioactives in Guam http://www.sms.si.edu/.
Illinois	Argonne National Laboratory	Argonne is a contributor to EC-US Task Force meetings on marine biotechnology topics
	The University of Illinois	The University is a contributor to EC-US Task Force meetings on marine biotechnology topics
	The University of Illinois Institute for Genomic Biology	Researchers are developing novel yeast strains that can carry out high-output fermentation of pentoses and galactose, the latter in collaboration with groups in the Republic of Korea, focusing on red seaweeds http://www.igb.illinois.edu/.
	The University of Illinois Energy Biosciences Institute	EBI produced an assessment of algal biofuels production (http://www.energybiosciencesinstitute.org/index.php?option=com_content&task=view&id=140&Itemid=1) in collaboration with the Lawrence Berkeley National Laboratory http://www.energybiosciencesinstitute.org/.
Maine	Center for Blue Biotechnology (CBB)	CBB, at The Bigelow Laboratory (http://www.bigelow.org/catt/bigelow-center-for-blue-biotechnology/) has received support from NIST (>$9M), US Congress ($1.5M) and the Maine Technology Asset Fund ($4.5M) to build a new facility, housing the Single Cell Genomics Center for DNA research on microbial cells from the environment http://www.bigelow.org/research/facilities/single_cell_genomics_center/. The Bigelow also hosts the Provasoli-Guillard National Center for Marine Algae and Microbiota containing one of the world's first combined collections of marine algae, bacteria, archaea and viruses https://ncma.bigelow.org/; the J J MacIsaac Facility for Aquatic Cytometry http://www.bigelow.org/research/facilities/; and the Geomicrobiology Research Laboratory http://www.bigelow.org/research/srs/david_emerson/. The Bigelow laboratory is a contributor to EC-US Task Force meetings on marine biotechnology topics.
Maryland	The DMB, University of Maryland	DMB (Department of Marine Biotechnology) has been formed after realignment of activities involving the Biotechnology Institute and the CoMB (Centre of Marine Biotechnology). DMB is responsible for fisheries and aquaculture research as well as marine microbiology, genetics, biodiversity and ecobiology http://www.umbc.edu/marinebiotech/overview.html.
	IMET, University of Maryland	CoMB was renamed IMET (the Institute for Marine and Environmental Technology) in 2010 http://imet.usmd.edu/about/overview.html. CoMB has been a contributor to EC-US Task Force meetings on marine biotechnology topics. IMET has programmes in molecular aquaculture http://imet.usmd.edu/research/sus_aqua.html, marine natural products http://imet.usmd.edu/research/marine_nat.html, marine bioenergy http://imet.usmd.edu/research/marine_bio.html and extremophile biotechnology http://imet.usmd.edu/research/extrem_bio.html as well as environmental genomics and metagenomics.

Massachusetts	WHOI	WHOI (the Woods Hole Oceanographic Institution) has a broad remit; in marine ecology, biology and biotechnology, as well as physical sciences. There are specific programmes on marine biofuels and co-products; marine natural products; marine lipids and biomedical applications; *in situ* genome analysis for monitoring; marine proteomics; ultra-high-resolution metabolomics; marine ecotoxicology. It has 3 ocean-going and 1 coastal research vessels and operates a number of submersibles http://www.whoi.edu/page.do?pid=77396.
Minnesota	University of Minnesota	The University was a member in the EU-funded project LIPOYEASTS
Mississippi	NIUST	NIUST (the National Institute for Undersea Science and Technology) was founded in 2002 by the NOAAA and the Universities of Mississippi and Southern Mississippi http://www.nurp.noaa.gov/NIUST.htm. One of its divisions is the OBCR Ocean Biotechnology Center and Repository, based at Uni Mississippi. OBCR manages a marine bioactives library, analysing and characterising the extracts for potential commercial use.
New Jersey	Rutgers University Center for Marine Biotechnology	RUCMB (http://sebs.rutgers.edu/centers/quickinfo.asp?RUCMB) is in the Institute of Marine and Coastal Sciences, and has research in algae for bioenergy http://sebs.rutgers.edu/research/archive.asp?10.
New York	Cornell University	Cornell is a contributor to EC-US Task Force meetings on marine biotechnology topics
North Carolina	Marine Biotechnology Center of Innovation	NCBC (the North Carolina Biotechnology Center) established the MBCOI in August 2011 with a four-year, $2.5 million grant, to accelerate commercial product development from marine bioresources using biotechnology in health, energy, aquatic food and diagnostics. The research feed-in comes from Duke University, East Carolina University, North Carolina State University, the University of North Carolina at Chapel Hill, and the University of North Carolina at Wilmington, with additional contributions from community colleges and various state-sponsored organizations and agencies http://www.mbcoi.net/.
Oregon	The Oregon Health and Science University School of Medicine	OHSU is a contributor to EC-US Task Force meetings on marine biotechnology topics. OHSU School of Medicine's Division of Environmental and Biomolecular Systems has projects in marine bioactives http://www.ohsu.edu/xd/education/schools/school-of-medicine/departments/basic-science-departments/environmental-biomolecular-systems/people/faculty/haygood.cfm.
Pennsylvania	Drexel University	Drexel is a contributor to EC-US Task Force meetings on marine biotechnology topics
South Carolina	Center for Coastal Environmental Health and Biomolecular Research, Charleston	This NOAA-funded Center hosts the Marine Biotechnology Program for Gulfbase http://www.gulfbase.org/organization/view.php?oid=mbp.

Infrastructures

The ATCC (American Type Culture Collection) is one of the most important repositories for living material, especially that associated with patentable inventions. For business in Europe and India it collaborates with LGC (UK).

HBOI maintains almost 50,000 samples of marine invertebrates and isolates of marine microbes within CMBBR's Marine Drug Discovery Program http://www.fau.edu/hboi/MarineDrugDiscovery/MDDcollection.php. HBOI's Media Labs maintain the website of marinebiotech.org, which brings together academic and industrial scientists from California, Florida, Massachusetts, Maryland, Mississippi and Oregon www.marinebiotech.org.

Private funding

Nereus Pharma, Albany Molecular and Estée Lauder are three companies involved in developing or marketing marine-derived products, the first two for health and the third for cosmetics use.

Bio Architecture Lab, based in Berkeley California with subsidiaries in Chile, has collaborations with Statoil, the Norwegian-based international energy company, and Innova-CORFO, the Chilean Economic Development Agency, to develop processes for the production of ethanol, renewable chemicals, fertilizers, proteins and other natural products from seaweed, a renewable and sustainable aquatic-based feedstock. http://www.ba-lab.com/.

Solazyme, innovators in algal biofuels, are in a partnership with Amyris, another US company producing plant-based biofuels, and Volkswagen of Germany, for a 12 month evaluation of biodiesels in VW's TDI Clean Diesel engines http://www.bizjournals.com/sanfrancisco/prnewswire/press_releases/California/2012/03/21/LA73691.

The J Craig Venter Research Institute is heavily involved in marine biodiversity mapping, metagenomics and synthetic biology http://www.jcvi.org/.

Sapphire Energy started up its algal biofuels plant in New Mexico in August 2012 http://www.sapphireenergy.com/. Sapphire invested US$16M and was supported by US$85M in private investment. It raised YS$144 in a Series C round in April 2012, including input from Monsanto Co. With a US$50M US DoE grant and a US$54.5M USDA loan guarantee, as part of development of its Columbus NM site for the 'algal crude' project, total funding to April was US$300M.

Trends

The re-election of President Obama suggests that the USA will continue to favour investment into microalgal biodiesel and jetfuel.

Asia

Overarching science strategies, plans and policies

Four of the most important players in marine biotechnology can be found in Asia - China, India, South Korea and Japan. Taiwan, Korea, Japan and India have specific national biotechnology strategies; in China, biotechnology is an integral part of the Five Year Plans. Individual Indian states have also established biotechnology policies (Gujarat for example). There are no separate national marine biotechnology strategies or policies except in Korea, where there is Blue-Bio 2016. In other major countries, marine biotechnology is mentioned as a specific topic in strategic plans or programmes (such as China, Japan's BioStrategy 2002 or India's 11th Five Year Plan). India also has a National Policy on Biofuels (2009) to which marine biotechnology is contributing. Korea has a plethora of strategies, policies and plans and marine biotechnology is an explicit part of the Biotechnology Fostering Policy.

Research funding schemes and programmes

Marine biotechnology is a specific part of China's National Hi-Tech R&D Programme '863'. The Chinese Academy of Sciences and Chinese government support Key Laboratories, some of which are focused on topics relevant to marine biotechnology. In India, DBT, the Department of Biotechnology, has a Task Force on Aquaculture and Marine Biotechnology, set up in 1998, which has funded over 200 projects since then. Japan was a leader in the area, establishing the Marine Biotechnology Institute in 1990, a public-private partnership, the lasting legacy of which appears to be only the national culture collection. Korea's Marine Bio 21 project (2004) has generated two genomics programmes, and the National S&T Plan 2008-2012 has Core technologies for New Industry: Marine Organism Conservation and Marine Biotechnology as one of its 7 investment areas.

Research priorities

There is also a broad range of topics across the countries. There is an increasing focus on biofuels in India but elsewhere, biodiscovery for human pharmaceuticals, food, feed and cosmetics is predominant. The Korean Institute of Ocean Science and Technology is a world-leader in marine biosciences and biotechnology. There are numerous institutes, research centres and universities in China, India and Korea substantially involved in marine biotechnology but they do need more complete profiling to understand how competitive they are with European activities and whether there are broader opportunities for international collaboration.

Infrastructures and coordination and support capacities/initiatives

Linkages are mainly attained through organised structures such as the key laboratories of China. In India, the Department of Biotechnology created a national Algal Biofuel Network in 2008.

National profiles

Bangladesh

A National Biotechnology Policy was elaborated 2004-2006 and prepared as a final draft in 2010, under the auspices of MOSICT (the Ministry for Science and Information and Communication Technology) www.mosict.gov.bd/index.php?option=com_docman&task=doc_download&gid=360&Itemid=390. A Biotechnology Roadmap was produced in 2010, which proposed an incubator for marine biotechnology development and the establishment of a marine biotechnology university course www.mosict.gov.bd/index.php?option=com_docman&task=doc_download&gid=361&Itemid=390. A

National Commission for Biotechnology was proposed, to work with NIB (the National Institute of Biotechnology http://www.nib.org.bd/) on research programmes. NIB is a body of MOSICT, with a proposed network of 6 laboratories including Fish Biotechnology, Fermentation and Bioprocessing, and Bioenergy and Fertilisation. A major project on microbial biodiversity and industrial use was funded 2006-2009.

China

National strategy for biotechnology

Biotechnology was included for the first time in the Seventh Five Year Plan of 1986-1990 and was enabled through the Ministry of Science and Technology's National Biotechnology Policy Outline. Biotechnology, including marine biotechnology, is one of China's strategic industrial sectors and is expected to benefit from government subsidies, positive tax treatment and preferential policies over the next decade, as part of the Twelfth Five Year Plan launched in 2010. As part of this, RMB 12B will be spent on new drug discovery and research. The new National Hi-Tech R&D Programme (the '863 Program') announced in March 2012, includes biotechnology and marine technology, albeit as separate topics. Within the Five Year and R&D plans, certain activities are identified as national key projects; marine biotechnology is making a contribution to some of these in the biomedical and environmental areas.

National strategy for marine biotechnology

There does not seem to be a national Marine Biotechnology strategy as such. However, marine biotechnology was first mentioned as a specific topic in the 863 Program in 1996 and has received significant and increasing support from the Eighth Five Year Plan onwards.

The CAS's Roadmap of Development in Chinese Marine Science & Technology to 2050[17] refers to the potential for marine bioresources to contribute strategically to energy-efficiency, emission-reduction, and development of fisheries, bio-based chemicals, marine microorganisms and marine microbial genetic resources, and links marine biotechnology with economic and social development. One of China's national strategic goals is "To Exploit the Sea Using Science and Technology", which includes MBt.

Programmes

Three National Programmes within the National Science and Technology Programme integrate research – the National Basic Research Programme (the '973 Program'), the National Key Technologies R&D Programme and the 863 Program. In 2006, about 30% of the 973 programme was for agricultural biotechnology and about 20% of the 863 programme was for biotechnology in general. The NSFC (National Nature Science Foundation of China) funds capacity-building and basic research abilities. MOST also provides the Innovation Fund for Technology-based firms IFT, which had a budget of US$21M in 2006.

Shanghai, Qingdao, Xiamen and Guangzhou are the four main regions for marine biodiscovery and bioactives development and commercial activity based on this. For example, in 2010, Qingdao's economic output in ocean science and technology, pharmaceuticals, environment protection, biological products and other products related to marine bioresources had grown from 85 B yuan in 2009 to 140 billion yuan, and even more investment in ocean R&D is planned.

At least 10 Chinese institutes specialise in marine biopharmaceuticals, notably the Ocean University of China, the First Institute of Oceanography, SOA, the Institute of Oceanology and the institutes of the Chinese Academy of Sciences. There are also some key laboratories at universities that conduct research and provide training in aspects of marine biotechnology. The Government has a cooperation programme with the EU that includes marine biotechnology – the Marine Bioproducts Engineering Group at Dalian, for example, has been involved in two FP5 EC consortia, SILIBIOTEC and UVTOX.

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[17] Xiang J (2010) pp 139-176 in *Marine Science and Technology in China: A Roadmap to 2050* ed. Xiang J Springer Verlag ISBN 978-3-642-05345-0

Since 1997, the government has funded research and investigation to link modern analytical and structural chemistry with the marine bioresources aspects of traditional Chinese medicine. Lux Research reports that, as a result of this, by 2010, the incremental output of the marine biopharmaceutical industry was CNY 9.5 billion (c. $1.5 billion), with annual growth of about 30% expected, according to the 12th Five-Year Plan[18].

Centres of marine biotechnology research

The National Research Center for Geoanalysis is a partner in the EU-funded project SPECIAL (sponge biotechnology).

IMCAS (the Institute of Microbiology, Chinese Academy of Sciences http://english.im.cas.cn/rh/rd/) launched the World Data Center for Microorganisms in 2011 http://english.im.cas.cn/ns/icn/201105/t20110518_69945.html. Amongst many collaborations, IMCAS is or has been a partner in EU-funded projects PharmaSea (unblocking bottlenecks for marine biodiscovery) and MGATech (enzymes from hypersaline lake microbes).

Dalian Institute of Chemical Physics (DICP): the Marine Bioproducts Engineering Group, established in 2000, works on novel biomolecules from marine sponges, biocatalysis and biotransformation, biotechnology for sustainable use of marine bioresources and hydrogen production from marine green microalgae http://www.english.dicp.ac.cn/04rese/07/group12.htm. DICP's Laboratory of Biotechnology, established in 2002, works in national key projects including biopharmaceuticals and natural biomolecules, biomaterials, renewable energy and environmental biotechnology http://english.dicp.cas.cn/rh/RS/bi/in/.

East China University of Science and Technology, Shanghai: the State Key Laboratory of Bioreactor Engineering is one of MOST's institutions. SKLBE's fields of activity include all aspects of bioreactor engineering in industrial biotechnology, biomaterials and tissue engineering and biomass energy. Marine biotechnology is mentioned as a specific topic http://sklbe.ecust.edu.cn/English/jianjie.php.

First Institute of Oceanography provides supportive marine science on the environment, marine resources and ecology of Chinese seas, nearby oceans and polar sea areas http://www.fio.org.cn/english/index.asp. Its Key Laboratory of Marine Bioactive Substances includes research into extreme environments and identifies, characterises and develops bioactives and bioresources suitable for foods, health foods, agrochemicals, medicines, biotechnology materials and platform chemicals.

Institute of Oceanology, Qingdao: the Key Laboratory of Experimental Marine Biology was the first ministry-level research facility in marine science in China. It focuses on resources exploration and sustainable utilisation in mariculture; issues and scopes are selection and safekeeping of strains, growth control to reproductive biology, genomics and bioinformatics, marine biotechnology, disease treatment and prevention, and natural bio-products R&D for pharmaceutical application. The Key Laboratory of Marine Ecology and Environmental Sciences (KLMEES) was founded in 2001 and provides background information for using marine bioresources http://english.qdio.cas.cn/rh/rd/klmees/.

Ocean University of China, Qingdao: the College of Marine Life Science houses two Provincial Key Labs of Marine Biotechnology, Marine Genetics and Breeding as well as the UNESCO Chinese Center of Marine Biotechnology, established in 1995 and working on marine yeasts and bacteria. The School of Medicine and Pharmacy also researches marine drug discovery and is a key laboratory of the Education Ministry http://www.ouc.edu.cn/english/academics/colleges/mediphar.html.

The State Key Laboratory of Microbial Metabolism at Shanghai Jiaotong University includes several Laboratories led by notable researchers, including the Zhi-yong Li lab, working on the microbial symbionts

[18] Xie X (2012) Convergence of Marine Biotechnology and Chinese Traditional Medicine – an untapped corporate opportunity. http://www.luxresearchinc.com/blog/coverageareа/china-innovation/ - scroll down

of marine invertebrates and their metabolites and metagenomics and the Jian-Jiang Zhong lab, applying bioprocess engineering, microbial fermentation and systems and synthetic biology to marine biotechnology http://life.sjtu.edu.cn/microbiology/En/content.aspx?info_lb=112&flag=68.

South China Sea Institute of Oceanology (SCSIO): the Hainan Key Lab of Tropical Marine Biotechnology is one of CAS's knowledge innovation institutes, with post-graduate programmes in Marine Biology, Physical Oceanography, Marine Geology, Marine Chemistry and Environmental Science http://www.scsio.cas.cn/. SCSIO has a programme on Sustainable Utilization of Tropical Marine Biological Resources, involving 3 key laboratories and 4 marine stations across South China[19]. SCSIO has collaborations with the USA, Japan, Australia, European and ASEAN countries, amongst others.

YSFRI (the Yellow Sea Fisheries Research Institute) researches environmental bioremediation, mariculture, molecular pathology, genetic improvement and marine bioactives and enzymes http://www.ysfri.ac.cn/english/index.asp.

Other Key Laboratories include Jiangsu Key Laboratory of Marine Biotechnology, Lianyungang and the Key Laboratory of Marine Biotechnology, Ningbo University, Zhejiang. Beijing University School of Environment and Energy has research in bioengineering for algal biofuels.

Infrastructures

China has 5 specific freshwater and marine culture or germplasm collections, and others associated with antibiotics, pharmaceuticals and industrial biotechnology http://www.wfcc.info/ccinfo/index.php/collection/col_by_country/c/86/.

Trends

A 'new marine biological products industry technology innovation strategic alliance', China's first, was launched in 2012. It is supported by the Ministry of Science and Technology, the Ministry of Agriculture, the National Development and Reform Commission, the Policy Research Office of the State Council and the State Oceanic Administration (SOA), it includes the seaweed fertilizer company Lei Li Gong, the Chinese Seaweed Industry Association, the China Agricultural Technology Promotion Association, Beijing Science and Technology [Association], Zhongguancun Science Park (National Innovation Demonstration Zone) and many other relevant bodies. The alliance will cover the whole range of activities involving the sustainable use of marine algae, fish and crustacean for marine product industry development, including marine polysaccharides, proteins and esters. Biotechnology approaches will include enzyme engineering and biological, chemical and fermentation engineering.

Private investment

Shanghai Zeyuan Marine Biotechnology Ltd is carrying out R&D in new microalgae culturing technology by a novel sequential technique of heterotrophic cultivation–dilution–photoinducement, and development and industrialization of related products such as lutein and astaxanthin from Chlorella http://www.zeyuanbio.com/e_profile.htm. Shanghai Zeyuan Bio is also scaling up enclosed photobioreactors and open pond and optimising large scale photoautotrophic cultivation of marine microalgae to produce bioactives and microalgae biodiesel, with the aim of establishing new microalgae bio-refinery technology. R&D input is provided by collaborations with the State Key Laboratory of Bioreactor Engineering in ECUST, the First Institute of Oceanography and SOA. Products include marine Bacillus probiotics for plant pesticide and fertiliser use. The Xunshan Group, the biggest producer of brown seaweed globally, is working with the US company Bio Architecture Lab on a large-scale seaweed culture and biorefinery project off the Shandong coast.

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[19] These are the Hainan Key Lab of Tropical Marine Biotechnology, the Guangdong Province Key Laboratories of Marine Drugs and Applied Marine Biology, the Hainan Tropic Marine Life Experimental Station, the Marine Biology Research Station in Daya Bay, the Marine Economic Animal Research Station in Zhanjiang City, and the Marine Plant Research Station in Shantou City.

India

National strategy for biotechnology

The first National Biotechnology Strategy (http://dbtindia.nic.in/biotech_strategy.htm) was approved in 2007-2008, over 20 years after the National Biotechnology Board and then the DBT (Department of Biotechnology) had been established (1982 and 1986 respectively). DBT manages development and funding in the overall area and puts 30% of its funds into public-private partnership activities in biotechnology. DBT works with the Science & Technology Councils of a number of individual states, including Gujarat, Rajasthan, Madhya Pradesh, Orissa, West Bengal, Haryana, Punjab, Jammu & Kashmir, Mizoram, Andhra Pradesh and Uttar Pradesh. Biotechnology Application Centres have been set up in Madhya Pradesh and West Bengal.

The Antarctic research activities, in which India has been involved since 1981, are the responsibility of the Ministry of Earth Sciences (MES, previously the Department of Ocean Development DOD).

DBT established the National Bio-resource Development Board NBDB in 1999, to help coordinate the development of India's biodiversity towards new products and processes. NBDB's remit includes marine bioresources.

Some States have established their own Biotechnology strategies: an example is the Government of Gujarat Department of Science and Technology Biotechnology Policy 2007-2012 http://btm.gujarat.gov.in/btm/pdf/bt-policy.pdf, which includes commentary on marine biotechnology.

National strategy for marine biotechnology

At national level, DBT has a Task Force on Aquaculture and Marine Biotechnology, set up in 1998, which oversees individual research projects and network projects with national and international partners. The 11th Five Year Plan (2007-2012) mentions marine bioresources as elements of the biotechnology/science & technology aspects, including bioresource development and utilization and increased productivity and disease management in aquaculture, in the report of the DPB and biotechnology working party http://planningcommission.nic.in/aboutus/committee/wrkgrp11/wg11_subdbt.pdf.

At state level, Gujarat identifies "the key activities in marine biotechnology … screening of marine resource for new molecules/active compounds, bio-prospecting of marine resource, conservation of marine bio-diversity, extraction of value added products and utilization of marine bio-mass etc. The state would focus on mangrove, sea weed and marine micro flora- fauna" http://btm.gujarat.gov.in/btm/mar-bio-indian-marine.htm. The plan includes a marine biotechnology centre, but remains to be fulfilled.

India's National Policy on Biofuels was released in 2009 and requires 20% blending of biofuel with petrol and diesel by 2017. In addition to work on land-based biomass and wastes, this has stimulated research and demonstration on algal biofuels, funded by DBT and the New Millennium Indian Leadership Initiative (NMILI). In addition to use of macroalgae for ethanol and biogas, there is a strong focus on *Botryococcus braunii* as a lipid-generating microalga. The US's NREL completed a report in 2010 that pinpointed a very strong future for India in algal biofuels, based on a combination of light, temperature, available land and availability of inputs. The report estimates that 45%-100% of India's diesel requirements could be replaced by algal biodiesel under favourable conditions and using no more than 10% of the current waste land area[20].

[20] Milbrandt A and Jarvis E (2010) *Resource Evaluation and Site Selection for Microalgae Production in India* NREL Technical Report NREL/TP-6A2-48380 Sept 2010 http://www.nrel.gov/docs/fy10osti/48380.pdf

Programmes

Although DBT is the major funder of biotechnology projects, there is increasing coordination with the other central organisations such as DST, CSIR, MES and ICAR (Indian Council of Agricultural Research), to avoid duplication of research funding. Under the Task Force on Aquaculture and Marine Biotechnology, DBT has funded over 200 projects since 1998. The biotechnology-based projects explore detection, monitoring or prevention of diseases of farmed fish and shellfish, including the use of bacteriophages, and detection of food-borne toxins and pathogens. There has also been work on establishing fish and shellfish cell lines and, increasingly since 2006, publications on bioactives (including antimalarial compounds), biosurfactants and other active molecules from marine microbes and macroalgae[21]. Water bioremediation using aquatic microorganism consortia is also a topic.

Network programmes currently under consideration are discovery and development of bioactives from marine actinobacteria, complete genome analyses of the important freshwater aquaculture fish *Labeo rohita* (Rohu, a carp) and *Clarias batrachus* (walking catfish), and a National Training Programme in molecular biology and biotechnology for fisheries professionals. DBT also supports Masters' programmes in marine biotechnology, mainly at Goa University and Cochin University of Science and Technology CUSAT. DBT's two most successful industry-focused programmes are the Small Business Research and Innovation Initiative SBIRI (www.sbiri.nic.in) and the Biotechnology Industry Partnership Programme BIPP (http://dbtindia.nic.in/uniquepage.asp?id_pk=680).

NMILI (New Millennium Indian Leadership Initiative http://www.csir.res.in/external/heads/collaborations/nmitli.htm) is a programme of DST (the Department of Science and Technology), supervised by DST's Council of Scientific & Industrial Research CSIR http://rdpp.csir.res.in/csir_acsir/Home.aspx?MenuId=1. It is currently providing R13 crore (US$2.65M) for a project Bio-fuel from marine micro-algae, involving 9 universities and research institutes, running from 2010-2013. This has already produced enough algal biofuel for test runs in a car using 20% biodiesel.

The DBT has helped fund Biotechnology Parks or Incubation Centres in Lucknow Uttar Pradesh, Bangalore Karnataka, and in Kerala, Punjab and Himachal Pradesh states. Guwahati Biotech Park Incubation Centre has recently been launched. There is some activity by State and Central Governments to assist industry in developing marine biotechnology, including infrastructure such as marine biotech science parks, research centres and training, but nothing is yet established. Examples of future plans include: Gujarat – a dedicated Marine Biotechnology Park at Jamnagar or Bhavnagar; Andhra Pradesh - a 218-acre Marine Biotech Park (MBP) in Visakhapatnam; Tamil Nadu – and investment of over US$11M in a Marine Biotechnology Park at Mamallapuram, with incubators for pharmaceutical, food supplements and cosmetic developments; Karnataka – a joint plan between the Department of Fisheries and the University of Agricultural Sciences Dharwad for a marine biotech park at Karwar. The University of Science and Technology at Cochin, Kerala, is planning a Centre for Marine Biotechnology to work on genotypic characterization, gene-sequencing and isolation of novel enzymes and marine natural products and biomaterials, as well as establishing a database on marine biotechnology.

Centres of marine biotechnology research

Marine biotechnology is carried out by CSIR-funded laboratories including the National Institute of Oceanography (NIO), Goa and Central Salt and Marine Chemicals Research Institute (CSMCRI) and Universities and establishments funded by the Department of Biotechnology (DBT), including structural and functional genomics, cultivation of seaweeds, bioprospecting and bioactives, microbial extremophiles, bioremediation. DBT's biotechnology work includes fish and crustacean farming, with aspects such as disease diagnostics and vaccine development, bioactive compounds and transgenics.

The National Institute of Oceanography in Goa works in bioprospecting, marine microorganism biotechnology, cultivation of marine organisms for industrial use, chemical synthesis of novel compounds

[21] Further information can be found in the DBT's Annual Reports for 2008-2009 and 2009-2010

from the sea, biofilms and biofouling; it is a participant in the EU-funded project MAREX http://www.niot.res.in/groups/osti/osti_activites.php. CSMCRI at Bhavnagar carries out functional genomics and other –omics to make use of coastal and marine bioresources, with metabolic engineering of systems of interest http://www.csmcri.org_/. Extensive work is carried out on natural chemistry of marine bioactives, on intensive seaweed aquaculture and value-added products including ethanol, and environmental applications of marine microorganisms including bioremediation. The University of Madras has used macroalgae to produce biogas through anaerobic digestion. ICGEB (the International Centre for Genetic Engineering and Biotechnology) has a programme on modification of microalgae for biofuels production.

The Antarctic research activities are led by the National Centre for Antarctic and Ocean research NCAOR, Goa, which plans and coordinates projects, sends expeditions to polar and oceanic regions, and is responsible for India's Maitri station in Antarctica http://dod.nic.in/ncaor.html.

A number of Universities offer MScs and/or PhDs in Marine Biotechnology, including Andhra University http://www.andhrauniversity.info/index.html, Visakhapatnam, focusing on fish and prawn cultural biotech; Goa University http://www.unigoa.ac.in/department.php?adepid=21, where the programme is direct-funded by DBT, with support by FIST-DST (the Dept of Science and Technology's Infrastructure Fund http://www.fist-dst.org/) since 2008, with research foci including marine enzymes, bioactives, bioremediation and risk assessment of rDNA in the marine environment; AMET University, Kanathur, working on marine bioactives and industrial applications and offering PhD and MPhil courses in marine biotechnology http://www.ametuniv.ac.in/coursemscmb.htm. Cochin University of Science and Technology offers an MTech in Marine Biotechnology.

ICAR's institutes CIBA (Central Institute of Brackishwater Aquaculture http://www.ciba.res.in/) and CIFA (Central Institute of Freshwater Aquaculture http://www.cifa.in/) are working with Nofima (the Norwegian Institute of Food , Fisheries and Aquaculture Research) to sequence the transcriptome and genome of the tiger shrimp. CIBA has a number of in-house and externally-funded projects in marine biotechnology, including genomics for abiotic stress, genomics for productivity enhancement and RNA vaccines for shrimp diseases. There is a co-funded mega-project 'Indo-Norwegian platform on fish and shellfish vaccine development', with involvement of 10 R&D laboratories in India including ICAR's institutes, the DBT-funded National Institute of Immunology, State and Central Universities and ICGEB, the International Centre for Genetic Engineering and Biotechnology, due to finish its first phase in March 2013.

Infrastructures

For algal biofuels, DBT created a National Algal Biofuel Network in 2008-2009. This involves 12 laboratories with activities in culture collections and repositories, strain improvement, production system development, and collection and characterisation. DBT is also co-funding with ICT a new national Centre for Energy Biosciences, which will have some aspect of marine bioenergy as yet undefined.

One of DBT's projects funded through the Task Force on Aquaculture and Marine Biotechnology has led to the establishment of a National Repository for fish and shellfish cell lines, based at the National Bureau of Fish Genetic Resources, Lucknow http://www.nbfgr.res.in/. This will host about 40 cell lines which have so far been developed, and will be available for academic and industry work.

Private investment

The broad biotechnology sector in India is well-established and growing, especially in human health and in nutraceutical areas. Many companies are active in extracting and selling carotenoids and other pigments from algae. Parry Nutraceuticals produces Spirulina for health supplements, but also extracts the blue food colourant phycocyanin from Spirulina and uses Dunaliella to produce beta-carotene. Mangalore Biotech (http://www.mangalorebiotech.com/) makes diagnostic kits for bacterial and viral infections in aquaculture, immunostimulants for shrimp culture and a marine bacteriophage-based product to treat Vibrio infections in farmed shrimp; the products were originally developed with funding from India's DBT

and licensed to the company by the research institutions involved. Poseidon Biotech, Chennai, has commercialised other DBT-funded inventions . Shantha Marine, based in Chennai, sells algal beta-carotene, algal lutein, alpha carotene, zeaxanthin and cryptoxanthin and beta-carotene fortified food products. GeoMarine Biotechnologies is a company providing probiotics for use in aquaculture.

Trends

DBT's industry-focused programmes SBIRI and BIPP are likely to be merged and managed by BIRAC (Biotechnology Industry Research Assistance Council), the Government of India's not-for-profit company that promotes biotechnology across the range from researchers to companies. BIRAC will deal with low risk and high risk projects in various sectors of biotechnology, IPR issues, bio-incubators, bio-clusters and commercialization aspects including policy matters.

The Central Government's 12th Plan will establish an Institute of Marine and Microbial Biotechnology, under the DBT (Department of Biotechnology). The budget is currently being finalised for Cabinet approval.

A Memorandum of Understanding has been signed with Norway for collaboration on disease prevention in Indian aquaculture, which will underpin further progress in projects such as the platform on fish and shellfish vaccines.

Japan

National strategy for biotechnology

The Biotechnology Strategy Council issued Guidelines in December 2002. BioStrategy 2002 incorporated 4 Bio themes – Bio-Medical, Bio-Agricultural, Bio-Ecological and Bio-Informatics. The contributions of these four activities to the overall Japanese biotechnology market were projected to reach 8.4 trillion Yen, 6.3 trillion Yen, 4.2 trillion yen and 5.3 trillion Yen respectively, by 2010. Bio-ecological included environmental and biofuels applications.

National strategy for marine biotechnology

Marine biotechnology was included in the 2002 BioStrategy Guidelines, in the context of marine bioactives, molecular aquaculture and disease prevention, and infrastructural support (training, industrial support and interdisciplinary projects).

Programmes

The 3rd Science and Technology Basic Plan (STBP) 2006-2010 http://www8.cao.go.jp/cstp/english/basic/index.html and the 4th STBP 2011-2015[22] provide the philosophical framework for practical approaches to R&D support. The 4th Plan includes green innovation and life innovation as two of its targets.

There is a Strategic International Research Cooperative Programme, the responsibility of the Department of International Affairs, which enacts those elements of the government's STBPs dealing with strategic promotion of international activities in science and technology http://www.jst.go.jp/inter/english/project/purpose.html. The Japan Science and Technology Agency (JST http://www.jst.go.jp/EN/) has been implementing the Strategic International Research Cooperative Programme since 2003, as designated by the Ministry of Education, Culture, Sports, Science and Technology on the basis of intergovernmental agreements. There are cooperations on marine biotechnology with CNRS France http://www.jst.go.jp/inter/english/project/country/france.html, bioenergy including marine microbes with CNPq Brazil http://www.jst.go.jp/inter/english/project/country/brazil.html, and marine science including algae with DIISR Australia http://www.jst.go.jp/inter/english/project/country/australia.html.

[22] See http://cis.ier.hit-u.ac.jp/Japanese/publication/cis/dp2011/dp534/text.pdf for a review of this

In 2004, the Nippon Foundation and the United Nations established a Japan Fellowship programme for Government officials and other professionals focusing on ocean-related topics, including coastal zone management and conservation and management of marine living resources http://www.nippon-foundation.or.jp/eng/ocean/scholarship/index.html. The programme is intended to raise knowledge and competence of international marine legal and management aspects, aligning with the UN's work in the Division for Ocean Affairs and the Law of the Sea (UN DOALOS).

Centres of marine biotechnology research

University-based centres include the Shimoda Marine Research Centre http://www.shimoda.tsukuba.ac.jp/eng-home.html at the University of Tsukuba, working on molecular biology, cell biology, genetics and the Biotechnology Research Centre http://www.pu-toyama.ac.jp/english/eindex.html at Toyama Prefectural University.

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC http://www.jamstec.go.jp/e/index.html) was inaugurated in 1990. In 2007, its budget was Yen 41.9B (approx €250M).

There is some economic development and industrial interest in marine biotechnology. The Japan External Trade Organisation (JETRO http://www.jetro.go.jp/en/reports) has an innovation collaboration programme JETRO-RIT, Regional Industry Tie-up; JETRO-RIT is supporting links between Hokkaido and New Zealand in the Hokkaido Bioindustrial Exchange with collaborations involving salmon skin collagen, salmon proteoglycan and marine functional foods https://www.jetro.go.jp/newzealand/Events/RIT2010.htm.

Infrastructures

The first substantial activity devoted to marine biotechnology was the establishment in 1990 of the Marine Biotechnology Institute, a 10-year project with over US$180M provided jointly by 24 Japanese companies and the Ministry of International Trade and Industry MITI. The lasting legacy of this is the Marine Biotechnology Institute Co Culture Collection at NBRC, the National Biological Resource Center http://www.nbrc.nite.go.jp/e/070328-e.html. Other centres within the National Institute of Technology & Evaluation Department of Biotechnology http://www.bio.nite.go.jp/pamphlet/e/nbrc-e.html include the Genome Analysis Centre (NGAC), the Biotechnology Development Centre (NBDC) and the Patented Microorganisms Depository (NPMD).

JAMSTEC has set up BISMaL, the Biological Information System for Marine Life, in 2009. This includes a publicly-accessible database of marine organisms, distribution, photographs and video based on information gathered by Japanese research vessels and submersibles http://www.godac.jp/portal/page/portal/bismal/AboutBISMaL/English. JAMSTEC also hosts the Marine Biological Sample Database http://www.godac.jamstec.go.jp/bio-sample/index_e.html, information on collections made by JAMSTEC vessels; and Extremobase http://www.jamstec.go.jp/gbrowser/cgi-bin/top.cgi, sequences from JAMSTEC's collection of extremophile organisms.

The NBRP (National Bioresource Project http://www.nbrp.jp/) aims to create systematic and complete collections of all Japan's biodiversity. The National Institute of Environmental Studies manages the NBRP algae project http://www.shigen.nig.ac.jp/algae/. Medaka and zebrafish are also included in NBRP, due to their involvement in experimental physiology, embryology, molecular biology and medicines-testing.

The Japanese Society for Marine Biotechnology has a range of members including chemicals, energy and health companies http://marinebiotechnology.jp/en/index.html.

Private funding

The biotechnology sector in Japan is strongly-established and was already worth almost US$20B in 2007, mainly pharmaceutical, food and chemicals activities, with well over 1000 companies. In November 2011 a joint venture was announced between three Japanese companies, IHI, Gene Technology YK and Neo-Morgan Laboratory Inc, IHI NeoG Algae LLC, to develop algal biofuels using the high-lipid producing Enomoto strain of *Botryococcus braunii*[23]. Tokyo Gas established a pilot plant that used anaerobic digestion to turn seaweeds into bioenergy some time ago but it is not certain whether this has proceeded to a full-scale plant.

Republic of Korea

National strategy for biotechnology

South Korea's first biotechnology development plan "Biotech 2000" spanned from 1994 to 2007 with a budget of Won 15.5 trillion (US$18B), with responsibilities shared across 7 government departments including Maritime Affairs and Fisheries. In 2006, the second national biotechnology development plan "Bio-Vision 2016" was launched, to continue until 2016, with Won 14.3 billion budget for project support. The main aim is to accelerate South Korea's economic development using biosciences and biotechnology so that it could join the ranks of the G-7 nations by 2010. Its goals are to foster a prosperous bio-economy and help create a healthy 'life-oriented' society. Part of the target is to gain 7th position in the world in number of patents and to build a market for Korean bio-economy products of Won 60 trillion. Five key biotechnology areas are defined, including life sciences; healthcare and medicine; food, agriculture and livestock; industrial processes/environment and maritime industry; and a bioconvergence industry. In addition, there will be actions to help gain broader public support and participation such as strengthening research ethics and life ethics guidelines and stepping up awareness and information efforts. BioVision 2016 is supported by 8 government agencies, including the Ministry of Science and Technology (in chief charge) and the Ministry of Education and Human Resources Development, with an annual rolling plan.

In 2011 the National Science and Technology Commission was reformed, with a stronger role in funding, driving and evaluating Korea's research and innovation agenda[24].

In 1996, an Ocean Development Plan was established, with a budget of US$33B for the following 10 years, including the establishment of a maritime management system, the exploration of resources at sea and the development of deep seabed mineral resources and energy; as well as international cooperation projects. This was replaced by Ocean Korea 21 for 2001-2010 and the Second Ocean Korea 21 for 2011-2020, which are intended to form a coherent and continuous plan for all marine, coastal and Economic Exclusion Zone activities. The 2nd OK21 excludes fisheries because of the disappearance of the Ministry of Maritime Affairs and Fisheries into MLTM (the Ministry of Land, Transport and Maritime – created by the merger of MOMAF with the Ministry of Construction and Transportation in February 2013). However, it does include marine bio-systems preservation and marine science & technology as elements, with macroalgal research and marine biodiscovery as part of these http://eascongress.pemsea.org/sites/default/files/document-files/presentation-st41-kim.pdf.

National strategy for marine biotechnology

Blue-Bio 2016 is a specific strategic plan for marine biotechnology. The Marine Biotech Supporting Centre under the Korean Institute of Marine Science and Technology works with the MLTM to manage the plan. There is an intention to establish a Marine Bio-resources Research Institute in 2013, with $145M investment. This will include Marine Bio-resources stock centres (culture collections), international

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23 http://www.ihi.co.jp/en/press/2011/2011-8-01/index.html accessed 27.8.12

24 See *Biotechnology in Korea* Ministry of Science, Education and Technology www.mest.go.kr; report downloadable from www.bioin.or.kr

collaborations for tropical, South Pole and North Pole explorations and construction of special research vessels. A Master Plan for Marine Biotechnology is being developed, building on the Biotechnology Promotion Act of 1983, Biotech 2000, Bio-Vision 2016 and Blue-Bio 2016. A Marine Bioresources Management Law was introduced in 2012.

MOMAF (Ministry of Maritime Affairs and Fisheries) has produced several documents concerning national marine strategy, including the Marine Development Basic Plan (1996) and Ocean Korea 21 (2000), in which marine research played a part. Marine biotechnology is an explicit part of the Biotechnology Fostering Policy, within Marine Biology and Fisheries, and is now a joint responsibility of MLTM and MFAFF (Ministry for Food, Agriculture, Forestry and Fisheries).

Programmes

Within the biotechnology development plans, several National R&D programmes and plans have been established, including the 21st Century R&D Program, the National Critical R&D Program, the Creative Research Initiative, the National Research Laboratory Program, the Basic Bioscience Program, the International Joint R&D Project and the Nanotechnology Development Plan http://english.mest.go.kr/web/1715/site/contents/en/en_0217.jsp. These form an umbrella to which marine biotechnology can contribute.

More specifically, in 2000, MOMAF produced planning and research reports concerning the future of marine BT and established the Marine Bio 21 Project in 2004, which established and supports a number of marine biotech-focused research centres in Korea, with a budget of 250B won (c. €175M in 2005) over 10 years. The fisheries and aquaculture main themes are the use of biotechnology for the restoration of fisheries resources, advanced aquaculture, the use of marine biota and gene resources (including novel bioactives and biomaterials), and exploitation into future major industries. The R&D budget for marine biotechnology projects was 3.4 billion won in 2001, 6.4 billion won in 2004, and 8.3 billion won (c. €6M) in 2005. The budget for 2007 was over 10 billion won (€10M).

Since then, two programmes in genomics have been established: Molecular Genomics of Marine & Extreme Organisms (MLTM) and Genome Research and Utilization of Marine Organisms (MAF) as part of the marine biotechnology development strategy.

In 2011, the Next Generation Bio-green 21 Project was announced, managed by the Rural Development Agency, with a budget of US$12B http://www.rda.go.kr/foreign/eng/agd_fht.jsp. Crop biotechnology is a major focus of the 7 national programmes within this, and the Program is supporting work on fermentation of red seaweeds for biofuels.

The National S&T Plan 2008-2012 has "Core Technologies for New Industry: Marine Organism Conservation and MBt" as one of its 7 investment areas.

Centres of marine biotechnology research

The Korea Ocean Research & Development Institute KORDI was renamed the Korean Institute of Ocean Science and Technology (KIOST) in mid-July 2012. As one of the Marine Bio 21 centres, the Marine Biotechnology Research Centre MBRC (renamed as the Marine Biotechnology Research Division) at KIOST is involved in exploration, sampling and biotechnology development of marine microbes, seaweeds and marine animals from a vast range of waters, including the Arctic, the Antarctic, tropical regions and deep-sea, as well as coastal area around the Korean peninsula http://mbrc.kordi.re.kr/?_p=introduction. Among those bioresources several selected microorganisms, algae and animals have being studied using genomic, metagenomic, transcriptomic and proteomic tools. Recently, MBRD has succeeded to sequence the genome of minke whale (*Balaenoptera acutorostrata*) and to find very interesting physiological features.

Omics technologies are further used to characterize populations and identify novel molecules, including enzymes such as epoxide hydrolases, agents to control biofilms, biomarkers for environmental stress and antimicrobial peptides. To promote the interest of the public in marine life, a pictorial book of 900 Korean macroalgal flora was published with 200 field pictures and genomic biomarker registration numbers. KIOST has wide international collaborations.

KOPRI (the Korea Polar Research Institute) works on relevant ecology and biology of Arctic and Antarctic land, ice and water http://eng.kopri.re.kr/home_e/contents/e_2160000/view.cms.

Various universities in Korea are involved in marine biotechnology and supporting activities, including:
The Division of Marine Environment & Bioscience, Korea Maritime University offering a Major in Marine Biotechnology, with training adapted to the needs of a number of industries that can benefit from marine biotechnology, including foods, aquaculture, feeds and natural products http://ocean-meb.hhu.ac.kr/;
The College of Ocean Science and Technology, University of Kunsan, active in a wide range of mariculture, fisheries and aquaculture science, with a department of Marine Biotechnology with interests in applying this to mariculture http://www.kunsan.ac.kr/eng/sub02/sub02_16.jsp;
Pukyong National University, hosting the Marine Bioprocess Research Center http://www.pknu.ac.kr/jsp_eng/research_a.jsp, the Marine Biochemistry Laboratory, the Ocean Life Science Research Center, the Maritime Transformation Research Center, and a Marine Disease Control and Prevention Center. The MBRC was established as a Marine Bio 21 centre with support of Won 6 billion. There is extensive research into novel bioactives and materials from marine species, developing the necessary bioprocesses for large-scale production, and managing sample collections;
Seoul National University's CMDD (Center for Marine Natural Products and Drug Discovery http://cnso.snu.ac.kr/eng/se07_re/se07_re_a/se07_re_a08/se07_re_a08.jsp) in the College of Natural Sciences, which is one of the Marine Bio 21 centres. New bioactives are isolated, characterized and screened for activity in metabolic diseases, immune diseases and infectious diseases, using target-based high throughput screening;
The Marine-bio center of Silla University in Busan, which houses companies active in developing and marketing marine-origin products, such as amBio.

Organisations working on marine biofuels include KITECH (the Korea Institute of Industrial Technology http://eng.kitech.re.kr/) and KIOST. The INHA Industry Partnership Institute has developed methods for making biofuels from [macro]algae. Kangwon National University has developed a method of using freshwater cyanobacterial species to produce fuel ethanol. Sungkyunkwan University is working on metabolically-engineered yeasts for fermentation of red seaweeds for biofuels, with the Samsung Advanced Institute of Technology and Seoul National University, supported by the BioGreen 21 Program. Sungkyunkwan University also holds patents on genetically-modified microalgae. Not only biofuel but also biohydrogen is now under development by KIOST, supported by MLTM. The biohydrogen is produced by marine hyperthermophiles using waste gases such as carbon monoxide from power plants and cheaper substrates such as formate, and the production plant is now being scaled up continuously.

A number of National Universities have departments of marine (or ocean) biotechnology, including Chungnam, Chonnam, Gyeongsang, Jeju (Cheju), Kangnung, Soonchunhyang and Sunmoon.

Infrastructures

The National Research Laboratory (NRL) programme was launched in 1999 to identify needs for research centres of excellence and support them in improving technological competitiveness. MEST provides approximately $250,000 a year for five years to each NRL project, of which there were over 440, mainly in universities and research institutes but including 52 in industry. Relevant NRLs included the Marine Molecular and Environment Biosciences Laboratory at Hanyang University (http://www.hanyang.ac.kr/user/indexFrame.action?framePath=div3_1.jsp&siteId=hanyangeng&leftPage=&rightPage=04_04_05.html&codyMenuSeq=1591) and the several NRLs in the field of marine biotechnology including Marine Microbial Diversity at KIOST.

NIBR (the National Institute of Biological Resources http://www.nibr.go.kr/english/main/main.jsp) was established in 2007, to house and expand national biodiversity collections (target 2.5 million samples by 2020) and make these available to bioindustry, as well as educate, and use molecular genomics for taxonomy. NIBR hosts the National Biological Resources Database.

MBRD at KIOST hosts the Marine & Extreme Bioresources Collections http://www.megrc.re.kr/MEBiC.

KOBIS (the Korean Ocean Biogeographic Information System http://kobis-en.kordi.re.kr/) is a member of the international OBIS system and provides marine biodiversity information to the main databases.

Private investment

With the strong support shown by the Korean government to biotechnology, the overall market for biotechnology-derived products, mainly human health and 'bio-foods', was estimated at US$6.5B in 2010[25]. A number of companies make more specific use of marine-origin materials, including Kittolife, with products based on high-purity, high-quality chito-oligosaccharides www.kittolife.co.kr; and amBio, which is investigating marine organisms and algae as probiotics and food or feed ingredients http://www.ambio.co.kr/eng/sub01/index.html. The US Company Unigen has a Korean subsidiary that uses extracts from marine organisms as ingredients in pharmaceuticals, functional foods, dietary supplements, cosmeceuticals, and animal health products http://www.unigenusa.com/.

Companies working on algae for carbon capture or energy production include SK Energy, which began investment in marine biofuels in 2008, Ecophyco Tech and Pegasus International.

SAIT (the Samsung Advanced Institute of Technology http://www.sait.samsung.co.kr/saithome/Main.do?method=main&pageKind=01) is involved in one relevant research project, developing the use of red seaweeds as biofuels, with Sungkyunkwan University, Seoul National University and the University of Illinois USA. SAIT operates a Global Research Outreach Program and issues calls for novel ideas in 15 areas including Energy, awarding US$50,000-$100,000 per project.

Pakistan

The Pakistan Atomic Energy Authority set up the National Institute for Biotechnology and Genetic Engineering in 1987. A National Commission on Biotechnology was established in 2001. MOST, the Ministry of Science and Technology, funds projects. Most work is in agricultural biotechnology. No known work on marine biotechnology at this moment.

Taiwan

National strategy for biotechnology

The National Promotion Plan for the Biotechnology Industry was first published in 1995 and revised every 2 years since then. A 'Diamond Action Plan for Taiwan Biotech Takeoff' was established in 2009, building on the Act for Development of Biotech and New Pharmaceuticals Industry (2008). The main focus is on human health applications, including genomics, and on supporting the development of the most active biotech-focused venture capital and investment industry in Asia. The Biotech & Pharmaceutical Industries Program Office in the Ministry of Economic Affairs is responsible for supporting the Promotion Plan.

[25] Burrill & Company http://international.burrillandco.com/regions-20.html accessed April 2012

National strategy for marine biotechnology

There is no specific marine biotechnology strategy. Elements of marine bioresource development are present in three aspects of the 'Newly Emerging Biotech' sub-sector, specialized biotech, agricultural biotech and environmental biotech.

Programmes

More information is needed.

Centres of marine biotechnology research

Several universities are involved in marine biotechnology including:
National Cheng Kung University;
The Institute of Marine Biotechnology http://www.imbt.ndhu.edu.tw/files/11-1051-8244.php at National Dong Hwa University, working on industrial applications of marine bioresources using biotechnology, and marine biomedical developments, in collaboration with the Government institution NMMBA (the National Museum of Marine Biology and Aquarium http://www.nmmba.gov.tw/english/ResearchA/College_of_Marine_Science);
The National Sun Yat Sen University, which offers undergraduate and post-graduate courses in marine biotechnology http://marine.nsysu.edu.tw/files/11-1023-4030.php;
The Institute of Marine Biology at the National Taiwan Ocean University, researching ecology, taxonomy and utility of marine organisms, including natural products chemistry, with activities in marine plankton, crustacean, phycology and marine fungi and viruses http://www.imb.ntou.edu.tw/introduction.htm.

The Middle East

Overarching science strategies, plans and policies

There appear to be no national biotechnology or marine biotechnology strategies, policies or plans. Israel had an economic development Bio-Plan 2000-2010.

Research funding schemes and programmes

Marine biotechnology seems to be fragmented and buried inside national research plans and programmes.

Research priorities

It is difficult to see what research topics might predominate. Israel is involved in sponge biotechnology, marine bioactives and marine biofuels. Turkey has activities in bioactives and in algal culture for bioenergy and biorefineries. Individual institutions are involved in a number of EU-funded consortia in marine biotechnology. Oman hosts the UNESCO chair in Seafood Biotechnology, at Sultan Qaboos University. There are new opportunities for algal biotechnology and molecular aquaculture in the region, such as Saudi Arabia's SABA algal biofinery project.

Infrastructures and coordination and support capacities/initiatives

CIESM and INOC represent the most important trans-regional activities; CIESM brings eastern Mediterranean countries together with North African and southern European countries; INOC brings the Middle East into contact with other Muslim nations spread across the world.

National Profiles

Iran

Department of Marine Biology, University of Marine Science and Technology, Khorramshahr-IRAN
Center for Biotechnology Research (PGBRC), Queshm Island, Iran.

Further information is needed.

Iraq

Further information is needed.

Israel

National strategy for biotechnology

Israel adopted a biotechnology economic exploitation strategy Bio-Plan 2000-2010, under the auspices of the Ministry of Industry & Trade. There is no specific biotechnology research strategy, but there are strategic research themes and a National Biotechnology Steering Committee. The Ministry of Science and Technology supports infrastructure, enabling scientific research and research with economic potential,

likely to produce new generation products for industrial, agricultural, medical and environmental sectors. Establishment of an infrastructure for biotechnology is one of its stated goals. There is also a joint strategic task force on biotechnology with USA, as part of the US-Israel Science and Technology Commission USISTC, established in 1993.

National strategy for marine biotechnology

None known.

Programmes

Israel is a member of the European Research Area http://ec.europa.eu/research/era/index_en.htm and qualifies for European funding.

Centres of marine biotechnology research

The National Center for Mariculture at Eilat works in fish biotechnology and seaweed farming http://www.ocean.org.il/Eng/ResearchInstitutesAndInfrastructure/NationalCenterToSeaAgriculture.asp
Ben-Gurion University, the Negev, has worked on microalgal cultivation and production of astaxanthin and was also a member in the EU-funded project GIAVAP with companies Rosetta Genomics and Alga Technologies;
The Hebrew University of Jerusalem hosts the Ruppin Academic Center School of Marine Sciences http://www.ruppin.ac.il/pages/1821.aspx;
The IOLR (Israel Oceanographic and Limnological Research Institute http://www.ocean.org.il/Eng/CompanyProfile/SeaAgriculture.asp) is a non-profit governmental corporation. One of its three research themes is Mariculture and Marine Biotechnology, involving the development and transfer of know-how for the local mariculture industry and associated biotech industries. IOLR's NCM, National Center for Mariculture, at Eilat, is involved in cultivation systems for marine organisms, genetic improvement of fish, prevention of maricultural diseases, new products and bioactives from marine sources and technology/knowledge transfer. It has generated two biotechnology startups in are areas of feeds for young fish and products to enhance fish reproduction;
The Kinneret Limnological Laboratory works on some microbial aspects of the Sea of Galilee, including toxin production in cyanobacteria http://www.ocean.org.il/Eng/ResearchInstitutesAndInfrastructure/LaboratoryResearchKineret.asp;
The NIO (National Institute of Oceanography, based at Haifa, hosts five research groups: Marine Chemistry, Marine Biology, Marine Biotechnology, Physical Oceanography and Marine Geology & Coastal Processes, active in the eastern Mediterranean, the Gulf of Aqaba and the Dead Sea. Research targets include innovative technologies for marine organism-derived food and biochemicals, medical uses of microalgal bioactives and advanced aquaculture and fish breeding;
Technion (Israel Institute of Technology)
Tel Aviv University Center for Renewable Energy http://english.tau.ac.il/renewable_energy is working with the NIO on seaweed co-culture in marine fish and shellfish aquaculture, with a view to pollution remediation and harvesting for biorefinery fractionation.
The Weizmann Institute has activities in biology, biochemistry, chemistry and marine biotechnology and is a partner in the EU-funded project SUNBIOPATH (increasing algal sunlight-to-biomass conversion) http://www.weizmann.ac.il.

Infrastructures

The Society of Israeli Aquaculture and Marine Biotechnology (SIAMB http://www.siamb.org.il/) promotes research in aquaculture and marine biotechnology and publishes the Israeli Journal of Aquaculture.

Jordan

The Marine Science Station (University of Jordan-Yarmouk University) is a partner in the EU-funded project ULIXES (using Mediterranean biodiversity for environmental remediation). Further information is needed.

Lebanon

The American University of Beirut is a partner in the EU-funded project MAREX (marine bioactives).

Further information is needed.

Oman

The Center of Excellence in Marine Biotechnology Sultan Qaboos University hosts the UNESCO chair in Seafood Biotechnology, with projects in value-added marine-origin products and detection and management of heavy-metal contamination of shellfish http://www.squ.edu.om/tabid/4393/language/en-US/Default.aspx.
Further information is needed.

Saudi Arabia

The King Abdulaziz City for Science & Technology KACST is Saudi Arabia's science agency and network of state R&D laboratories. It is involved in policy-advising and in enacting R&D support strategies, as well as conducting basic and applied research. Biotechnology and nanotechnology are two of the 11 R&D areas. The Science and Technology National Policy aims to develop Saudi Arabia's science base and R&D application and innovation in accord with national and religious requirements, and spans the period 2005-2025.

SABA, the Saudi Arabia Biorefinery from Algae project, has been started with funding from KACST, based on a previous small-scale applied R&D project. The first phase is the isolation and investigation of Saudi coastal microalgae to select those with are hyper-producers of algal lipids. The project is a collaboration between King Saud University, KSU's King Abdullah Institute for Nanotechnology and two Portuguese institutions, CCMAR (Marine Sciences Centre, University of the Algarve, Faro) and IBB (Institute for Biotechnology and Bioengineering, Lisbon) http://www.ecomena.org/saba-project/.

King Saud University has several algal-oriented activities, including investigation of algal bioactives.

More information is needed.

Syria

More information is needed.

United Arab Emirates

Abu Dhabi, Ajman, Dubai, Fujairah, Ras al-Khaimah, Sharjah, and Umm al-Quwain.

More information is needed.

South-East Asia & Indian Ocean islands

Overarching science strategies, plans and policies

Thailand and Vietnam stand out as the countries most focused on marine biotechnology. Indonesia, Malaysia, Singapore, Sri Lanka, Vietnam and Thailand have national biotechnology strategies, plans or policies. Only The Philippines, with NARRDS, the National Aquatic Resources Research & Development System, and Vietnam, with a recently-issued letter from the President of VAST (Vietnam Academy of Science and Technology) explicitly calling for increased efforts in marine biotechnology, have anything resembling a marine biotechnology policy or strategy.

Research funding schemes and programmes

There is evidence of strong investment in biotechnology, but less so in marine biotechnology. The Ninth Malaysia Plan 2006-2010 allocated almost US$550M to industry development through biotechnology and Thailand's National Biotechnology Policy Framework (2004-2009) allocated about US$125M to biotechnology. There are few specific programmes involving marine biotechnology; one is the PharmaSeas Drug Discovery program, funded by the Philippines under NARRDS (National Aquatic Resources Research & Development System). Indian Ocean islands are sometimes involved in marine biotechnology activities, notably Madagascar, but more information is needed.

Research priorities

Much of the focus seems to be on exploitation of natural biodiversity for novel bioactives. In Vietnam and Thailand, there is however significant molecular aquaculture, especially for crustacea (shrimps, prawns). Regionally-important research resources include University of Diponegoro Indonesia, the University of the Philippines Marine Science Institute and UP-Visayas, Thailand's National Center for Genetic Engineering and Biotechnology (BIOTEC), the Center of Excellence for Marine Biotechnology at Chulalongkorn University Bangkok, and several institutes within the VAST network in Vietnam.

Infrastructures and coordination and support capacities/initiatives

The Association of South East Asian Nations (ASEAN) may assist in trans-regional activities but this is not clear. The Indonesian Dept of Marine Affairs and Fisheries established a scientific forum for Indonesian Marine Biopharmaceuticals in 2005, and in Vietnam the Ho Chi Minh City Biotechnology Park was started in 2010, with the intention of housing biotechnology start-ups in the aquaculture, seafood and environmental sectors.

The member states of ASEAN, the Association of Southeast Asian Nations, are Brunei Darussalam, Cambodia, Indonesia, the Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Vietnam. ASEAN's Dialogue Partners include China, Australia, the EU, India and Japan. Indian Ocean islands include The Maldives, Mauritius and Madagascar.

National profiles

Brunei Darusssalam

There are mariculture projects in Brunei, and biodiversity/ecology research, but little or no evidence of marine biotechnology.

Cambodia

No Biotechnology or Marine Biotechnology strategies are in evidence. There is a National Capacity Action Plan 2007-2016 responding to UN Conventions, and the National Biodiversity Strategy and Action Plan and a Government Rectangular Strategy 2009-2013 (which mentions fisheries reforms and making better use of natural resources including biodiversity). These all focus on prevention of damage to biodiversity rather than sustainable development and usewww.cbd.int/doc/world/kh/kh-nr-04-en.pdf.

Indonesia

More than 75% of Indonesia is coastal and marine; it has the second-longest coastline after Canada. As an area of great biodiversity, it has great promise for marine biodiscovery. A recent paper describes numerous new molecules found in Indonesian marine invertebrates and microbes[26]. The Ministry of Marine Affairs and Fisheries is responsible for marine biotechnology.

National strategy for biotechnology

A national science and technology policy was established in 1990, with biotechnology as one of the priorities. An Indonesian Biotechnology Consortium has been founded, bringing over 30 institutes together, which formulated a national biotechnology strategy programme in 2004.

Some activities were proposed after 2000, including a 'Bio-Island' in Rempang, intended to be a special economic zone for research and commercialisation of biotechnology (including marine biotechnology) and a Bio-park in Serpong West Java as a centre for biodiversity exploration, biodiscovery, culture collections and gene banks. These were to be government-supported, through the Ministry of Science and Technology.

National strategy for marine biotechnology

There is no obvious national strategy for marine biotechnology.

Centres of marine biotechnology research

A number of Universities have groups involved in marine biodiscovery and biotechnology, including those of Diponegoro, Gadjahmada, Sam Ratulangi, and Bogor Agricultural Institute, the Marine Fisheries Agency's Ekowati Chasanah Research Centre for Marine and Fisheries Product Processing and Biotechnology. The University of Diponegoro's Center for Tropical and Coastal Studies http://www.undip.ac.id/ is a partner in the EU-funded project MARINE FUNGI, which is aiming to isolate new anticancer drugs from marine fungi.

Infrastructures

The Department of Marine Affairs and Fisheries established a scientific forum for Indonesian Marine Biopharmaceuticals in 2005, as a network of researchers, government and industry.

[26] Tubun KS and Petamburan VI (2008) Marine Biodiscovery research in Indonesia: Challenges and Rewards *J Coastal Development* 12 (1): 1-12

Lao People's Democratic Republic

The National Authority for Science and Technology NAST was established in 2007 and has a Biotechnology Center.

Malaysia

National strategy for biotechnology

Malaysia's New Biotechnology Policy was announced in 2005, covering the period to 2020. The NBP includes agricultural and industrial biotechnology.

National strategy for marine biotechnology

There is no obvious national strategy for marine biotechnology.

Programmes

The Ninth Malaysia Plan 2006-2010 allocated almost US$550M to biotechnology industry development, some of this funnelled through the Malaysia Biotech Corporation, part of MOSTI, the Ministry of Science, Technology and Innovation.

Centres of marine biotechnology research

The School of Biological Sciences, University of Malaysia, Penang has departments of Aquatic Biology and Biotechnology http://bio.usm.my/index.php/programmes/postgraduate/biotechnology. There is also a Faculty of Biology at the National University of Malaysia, Selangor http://www.ukm.my/bsbt/. Although the School of Biosciences and Biotechnology at Universiti Kebangsaan Malaysia http://www.ukm.my/ has study and research programmes in molecular biosciences and biotechnology, there is no mention of marine science.
The School of Engineering and IT http://sktm.ums.edu.my/sktmv2/Default.asp at the University Malaysia Sabah has some work on engineering of algal biofuels and there is an Institute of Biotechnology http://www.ums.edu.my/ipb/index.html.

Infrastructures

There is no evidence of any directed towards marine biotechnology.

Private investment

The biotechnology industry overall is projected to contribute c. US$75B to Malaysia's economy by 2020. BiotechCorp expects to establish over 100 new companies, many through a programme called BioNexus, with about 30% of its investments going into agricultural companies, thoough none appear to have a marine focus. Algaetech International is based in Kuala Lumpur, selling microalgal products for nutrition and health supplements, and is also developing algal systems for biofuels, waste water management and CO_2 sequestration http://algaetech.com.my/. Current demonstration projects include a CO_2-trapping system installed at a power plant in Indonesia, using photobioreactors for algal cultivation; current development projects focus on biofuels and high-value products such as astaxanthins.

Myanmar

Little information except that a number of Universities are involved in marine science and/or biotechnology, e.g. Mawlamyine University, MandalayTechnological University and the Technological University Dawei.

The Philippines

DOST (the Department of Science and Technology) funds, and PCAARRD (the Philippine Council for Agriculture Aquatic Resources Research and Development) coordinate the National Aquatic Resources Research and Development System (NARRDS) and its R&D projects and programs. One of the NARRDS programmes is The Philippine PharmaSeas Drug Discovery Program. PharmaSeas is focused on bioactives from marine organisms, including anti-infectives from sponges and their symbionts and further exploration of pain-control using marine snail venoms http://www.pia.gov.ph/news/index.php?article=631332142905.

The first biotechnology establishment in the Philippines was the National Institute of Molecular Biology and Biotechnology at the University of the Philippines at Los Baños (UPLB). Of the four national centres that are part of NARRDS, UP-Marine Science Institute (UPMSI) and UP in the Visayas (UPV) are involved in marine biotechnology R&D and UPLB is involved in industrial and agricultural biotechnology. UPMSI is the lead on the PharmaSeas programme and also works in ecoinformatics, culture optimisation and molecular characterisation to support marine bioresource development. Macroalgal research is carried out by several colleges and government centres, including UPMSI (which hosts the Seaweed Information Center in Quezon City); the Colleges of Fisheries at UPV and at Bicol University; the Marine Biological Laboratory at Silliman University; the University of San Carlos; the Southeast Asian Fisheries Development Center, Iloilo; and the Fisheries Resources Research Division, Bureau of Fisheries and Aquatic Resources. The Philippines is a major producer of seaweeds and marine colloids.

Singapore

A National Biotechnology Development Strategy was established in 2000. Singapore has invested heavily in biotechnology but this is entirely devoted to human genomics, human healthcare and advanced biomedicine. There has been some investigation of bioactives from marine organisms but marine biotechnology activity is not high. Research at NUS, the National University of Singapore http://www.nus.edu.sg/, includes marine biotechnology (in Microbiology, Systems Biology/Biotechnology Group) but NUS's Marine Biology Laboratory http://www.dbs.nus.edu.sg/lab/MBL/index.html does not seem to have links with NUS's Biotech Cluster Group. Some private investment is noted, including investment into use of freshwater sponges to clean up wastewater contaminants, by the Singapore Delft Water Alliance SDWA http://www.porifarma.com/index.php?option=com_content&task=view&id=18&Itemid=29, whose Dutch partner is Porifarma BV, founded 2008-9 but it is not clear what progress has been made so far. One company MerLion Pharmaceuticals works with extensive natural product collections, including some of marine origin.

Sri Lanka

There is a National Committee on Biotechnology and a National Plan 2009-2015 but there is very little public investment in biotechnology, including marine biotechnology.

Thailand

The importance of shrimp-farming and other aquaculture has resulted in a long-term commitment to advanced aquaculture, genetics and genomics, and biotechnology for disease diagnosis and control. In addition to the Government-sponsored National Center for Genetic Engineering and Biotechnology, there are departments of marine science or biotechnology at numerous universities, which often collaborate on projects, for example studying bioactives from sponges.

National strategy for biotechnology

The National Biotechnology Policy Framework of 2004-2009 committed Thailand to investment of over 5B baht (c. US$125M). The Thailand Board of Investment supported this with significant subsidies and incentives for biotechnology-based operations, including R&D activity and manufacturing of biomolecules and bioactives from microorganisms and cells, molecular diagnostic kits and animal improvement using biotechnology.

National strategy for marine biotechnology

There is no specific marine biotechnology strategy.

The shrimp sector is one of Thailand's major export earners and is thus a strategic target for biotechnology, through molecular diseases diagnosis, disease control through vaccines, and disease prevention through genetic selection of clean (Specific Pathogen Free) and resistant broodstock and larvae.

Programmes

Centres of marine biotechnology research

BIOTEC (the National Center for Genetic Engineering and Biotechnology) is government-funded. BIOTEC was leader for the Asia-Pacific Genome Consortium established in 2004. The Bioresources Technology Unit http://www.biotec.or.th/btu/, established 2007, manages BIOTEC's culture collection and carries out some marine biotechnology work, mainly on marine fungi and their metabolites.

The Marine Biological and Fishery Research Institute, Department of Fishery, Phuket http://www.pmbc.go.th/ was founded in 1968 as part of the Denmark-Thailand cooperation agreement and includes aquaculture and marine natural products development in its remit, including coastal mangrove ecology as well as marine systems.

Academic centres of marine bioscience and biotechnology, and groups involved in support activities including bioactives characterisation, include departments and units at Burapha University, Chulalongkorn University, Chulalongkorn University, King Mongkut's Institute of Technology, Mahidol University, Naresuan University, Prince of Songkla University, Rajamangala University of Technology, Srinakharinwirot University, Walailuk University.

Of these, Chulalongkorn University, Kasetsart University and Mahidol University appear to have the strongest presence in molecular aquaculture, bioactives and related marine biotechnology activities:

Chulalongkorn University, Bangkok hosts Thailand's Center of Excellence for Marine Biotechnology (CEMB http://www.sc.chula.ac.th/department/Marine_Science/mrinter.htm#Marine), founded in 1987 by BIOTEC and Chulalongkorn University as the Marine Biotechnology Research Unit, becoming the CEMB in 2003. It is staffed by researchers from BIOTEC and academic staff from Chulalongkorn and Srinakharinwirot Universities.

Research includes improvement of aquaculture systems, fish and shellfish broodstock performance and sustainable aquatic plant culture; aquatic environmental biotechnology for closed re-circulating seawater systems for aquaculture and biomarkers for water pollution life-cycle nutrition of farmed shrimp species; probiotic micro-organisms for improving growth and immune responses of farmed shrimp and fish; and the biology of culturable marine species that are potential natural producers of bioactive compounds.

Kasetsart University has activities in marine biotechnology including algal and microbial bioactives http://fish.ku.ac.th/EngHistory.html and Mahidol University's Institute of Molecular Sciences researchers shrimp molecular biology http://mahidol.ac.th/

Infrastructures

The BIOTEC Genome Institute houses the genomes of shrimp and Spirulina. BIOTEC also hosts the Thai Culture Collection http://www.biotec.or.th/en/index.php/research/research-unit/25-gi.

Vietnam

National strategy for biotechnology

A Development Programme in Biotechnology was established in 1994 for the period 1995-2010 managed by MOSTE, the Ministry of Science, Technology and the Environment. A National Commission on Biotechnology was established in 1997.

National strategy for marine biotechnology

There is no national strategy for marine biotechnology. However, VAST, the Vietnam Academy of Science and Technology, issued a President's Letter in August 2012 that foresees increased efforts in ecology and marine biotechnology for sustainable use of Vietnam's marine biodiversity, noted as one of the 16 top 'hot spots' in the world (for the English text of this, see http://www.vast.ac.vn/en/index.php?option=com_content&view=article&id=1188:investigating-and-accessing-vietnams-marine-biological-resources&catid=28:national-science-and-technogory-news&Itemid=34. There is a State Biofuel Development Program of 2007, which provides a framework for use of marine biomass for bioenergy.

Centres of marine biotechnology research

VAST http://www.vast.ac.vn/index.php, has several institutes relevant for marine biotechnology, including Ecology and Biological Resources[27], Natural Products Chemistry[28], Marine Environment and Resources[29], Biotechnology[30] and NITRA, the Nhatrang Institute of Technology Research and Application[31]. NITRA works on genetic resources and cultivation improvement for seaweeds, high-value enzymes from marine organisms, biotechnology for aquaculture development and new bioactives.
The Institute of Biotechnology at the National Centre of Natural Science and Technology researches microorganisms and basic biotechnology.

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27 http://www.vast.ac.vn/index.php?option=com_content&view=article&id=439%3Aviensinhthaitnsv&catid=42%3Acac-vin-nghien-cu&Itemid=103&lang=en

28 http://www.vast.ac.vn/index.php?option=com_content&view=article&id=370%3Avhhchctn&catid=42%3Acac-vin-nghien-cu&Itemid=103&lang=en

29 http://www.vast.ac.vn/index.php?option=com_content&view=article&id=375%3Avttnvmtb&catid=42%3Acac-vin-nghien-cu&Itemid=103&lang=en

30 http://www.vast.ac.vn/index.php?option=com_content&view=article&id=379%3Avcnsh&catid=42%3Acac-vin-nghien-cu&Itemid=103&lang=en

31 http://www.vast.ac.vn/index.php?option=com_content&view=article&id=452%3Avin-nghien-cu-va-ng-dng-cong-ngh-nha-tran&catid=42%3Acac-vin-nghien-cu&Itemid=103&lang=en

Several Universities in Vietnam are involved in marine biotechnology:

The Institute of Microbiology and Biotechnology at VNU, Vietnam National University http://www.vnu.vn/en/contents/index.php?ID=939 hosts the Vietnam Type Culture Collection VTCC and works on biodiversity, taxonomy, enzyme and protein technology, molecular genetics, microbiology, microalgae, fungi, fermentation and downstream processing technology. IMB uses genomics to identify potential novel bioactives with applications in medicine, agriculture, and food processing;

The Department of Aquatic Resources Management carries out some biotechnology work concerned with discharge reduction for fish and seafood production; molecular biotechnology is included in the degree course http://www.wix.com/iuaquatic/ardweb;

The Department of Biotechnology at Ho Chi Minh International University works on marine bioactives and biofuels, advanced aquaculture and environmental remediation http://csc.hcmiu.edu.vn/biotechnology/index.php/deparment-of-biotechnology/research;

Ho Chi Minh City Medicine and Pharmacy University was a partner in the EU-funded project COLORSPORE, which aimed to find new natural carotenoids from, among other organisms, marine *Bacillus* species;

Ho Chi Minh City Biotechnology Center has developed PCR-based tests for shrimp diseases.

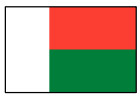
Seaweeds are farmed in Vietnam for food and industrial purposes, including *Kappaphycus alvarezii*, *Sargassum* and *Gracilaria tenuistipitata*, and these are being investigated for biofuels use.

Infrastructures

Work on the Ho Chi Minh City Biotechnology Park began in 2010 with an investment of US$100M, incorporating the HCMC Biotechnology Center. 6 of the 12 planned laboratories will be used for aquaculture, seafood and environmental biotechnology.

Indian Ocean islands

Madagascar



The National Oceanographic Data Centre at the University of Toliara_is involved in the protection of coastal reefs and marine biodiversity assessment in south-western Madagascar and bio-ecological surveys to facilitate the development of a sustainable marine park in the Masaola area in the north-east. The Data Centre records include almost 6,500 records of corals, diatoms, dinoflagellates, invertebrates and fish. The University of Antananarivo is working on photobioreactor culture of microalgae for bioremediation, biomolecules and Bioenergy; organisms mentioned include Chlorella, Spirulina, Porphyridium and other species http://www.univ-antananarivo.mg/.

Madagascar is the Earth's 4th largest island and its marine resources seem to be particularly rich in diversity and attract collaborative international projects, such as The Sea Around Us (University of British Columbia), examining use and abuse of fish resources; Biodiversity conservation and drug discovery in Madagascar (University of Maryland supported by NIH International Cooperative Biodiversity Group $4.5M 2008-2013); and collection of algae and cyanobacteria by the Scripps Institution of Oceanography Center for Marine Biotechnology and Biomedicine.

Maldive Islands

Further information is needed.

Mauritius

In 2003, the Ministry of Agriculture, Food Technology and Natural Resources proposed the Mauritius Agricultural Biotechnology Institute (MABI), with a budget of Rs. 360M, expected to start operating in 2008. Whether this includes marine biotechnology is not known.

More information is needed on **La Réunion**.

Australia-Pacific

Overarching science strategies, plans and policies

Both Australia and New Zealand have biotechnology strategies but neither has a specific marine biotechnology strategy. In New Zealand, the Biotechnology strategy includes marine biotechnology within environment/industry, and MoRST (Ministry of Research Science and Technology) produced a roadmap for biotechnology research in 2007, which included marine biotechnology as a specific component.

In Australia, enhancement of access to marine resources and marine science are mentioned in the National Biotechnology Strategy (2000-2008) and its successor '*Powering Ideas – An innovation agenda for the 21st century*', but marine biotechnology is not explicitly included. Australian States including Queensland and Tasmania do however include marine biotechnology as part of their research and economic development strategies. Marine Innovation South Australia includes and Aquaculture, Biotechnology and Biodiscovery Science group. Of the Pacific Islands, Guam and Fiji seem the most active in marine biotechnology. There are no obvious national strategies, but Fiji was an early mover in biodiversity (Access and Benefit-Sharing) policy development.

Research funding schemes and programmes

Australia's 'Super Science Initiative' plans to put A$1.1B into innovation science 2009-2013, approximately 45% into biotechnology, including marine biology in one of the 'Future Industries' themes. Australia already supports a world-class basic and applied research institute, AIMS (Australian Institute of Marine Sciences). Australia has also established the Industrial Transformation Research Program in 2011, with $236M funding, though it isn't yet clear how much of this might be applied to marine biotechnology.

Research priorities

The New Zealand Ministry of Research, Science & Technology's roadmap for biotechnology research recognises molecular aquaculture and marine bioactives as two of New Zealand's research strengths.

Infrastructures and coordination and support capacities/initiatives

The Australian Cooperative Research Centres (CRCs) provide translational services for industry and several of these have taken part in marine biotechnology-orientated work, in seafood genetics, Antarctic microbiology and bioremediation.

Australia

National strategy for biotechnology

Australia's first National Biotechnology Strategy spanned 2000-2008 http://www.cbd.int/doc/measures/abs/msr-abs-au4-en.pdf. Following on from this, "*Powering Ideas - An innovation agenda for the 21st century*" http://www.innovation.gov.au/innovation/policy/pages/PoweringIdeas.aspx was published by the Australian government in 2009 and included biotechnology as one of four key technologies, noting that Australia was one of only 6 countries deemed capable of benefiting from sixteen future applications arising from biotechnology, nanotechnology, materials science and information technology. The other five were Canada, Germany, Israel, Japan, Korea and the USA[32]. The Government then published the National Enabling Technologies Strategy in 2012, within a Super Science – Future Industries initiative and with a budget of A$38.2 over 4 years http://apo.org.au/research/national-enabling-technologies-strategy. "Cutting-edge" biotechnology is part of this.

National strategy for marine biotechnology

The National Biotechnology Strategy included enhancement of access to marine bioresources as one of its goals and marine science is specifically mentioned in "*Powering Ideas*". Marine biotechnology *per se* is not mentioned in either of these documents.

Individual states within Australia have responsibility for their coastal waters to 3 nautical miles off-shore, and then the Federal Government takes responsibility for waters to the limit of the Economic Exclusion Zone. Several states include marine biotechnology in their development strategies, including Queensland, Western Australia, South Australia and Tasmania. Life Sciences Queensland notes that marine biotechnology is part of the state's plans for sustainable economic and social growth http://www.lsq.com.au/AboutLSQ.aspx. The Western Australian Marine Science Institute (http://www.wamsi.org.au/) in its Node 5 activities led the development of WA's marine biotechnology strategy. An Aquaculture, Biotechnology and Biodiscovery Science group is part of Marine Innovation South Australia (http://www.misa.net.au/). "*BioVision Tasmania 2007-2015*" http://trove.nla.gov.au/work/35441139 identifies 3 niche strengths for the State of Tasmania – agriculture, forestry and environmental biotechnology; aquaculture, marine, Antarctic and Southern Ocean biotechnology; and population genetics for human health biotechnology. In Blue Biotech, Tasmania is focusing on marine extracts and Antarctic and Southern Ocean bioactives. About 10% of the state's biotechnology industry employees work in marine-related companies. The Tasmanian Aquaculture and Fisheries Institute is the applied research organisation for marine bioresource management.

Programmes

The Super Science Initiative that was announced in May 2009 will contribute A$1.1 billion to priority areas of Australian research until 2013 http://www.innovation.gov.au/Science/ResearchInfrastructure/Pages/SuperScience.aspx. "Future Industries", one of the three categories qualifying for support, includes marine biology. Biotechnology as an overall topic will benefit from A$500M over this period and Marine and Climate topics have been allocated over A$385M, including tropical marine infrastructure support at AIMS (the Australian Institute of Marine Science).

Photobioreactor-based recombinant microalgal protein and biofuels work at SARDI (the South Australian Research and Development Agency) is being funded by NCRIS, the National Collaborative Research Infrastructure Strategy programme http://ncris.innovation.gov.au/Capabilities/Pages/BiotechProds.aspx#Biofuels.

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[32] From Wong A (2007) *The Global Technology Revolution 2020* American Association for the Advancement of Science EP-200705-28

Centres of marine biotechnology research

AIMS, the Australian Institute of Marine Science, was set up by the Australian Government in 1972 and describes itself as a 'tropical marine research agency' http://www.aims.gov.au/. It receives over A$31 million in public funding and its main research areas are marine biotechnology, biodiversity assessment, climate change and water quality. AIMS's marine biotechnology focuses on discovery of marine natural products for pharmaceuticals, industrial and environmental applications, providing applied research for sustainable supply of fine chemicals by aquaculture, fermentation, or gene expression. Marine microbiology and ecotoxicology are strengths. CMMG (the Centre for Marine Microbiology and Genetics Research http://www.aims.gov.au/docs/research/marine-microbes/microbes/cmmg-index.html) sits within AIMS and is a microbiological and genetic research laboratory with experimental aquaria that have level 2 containment and quarantine certification. One of CMMG's functions is to generate commercial supplies of lead compounds for biotechnological applications. AIMS has an agreement with the UK company Aquapharm to supply Australian marine microorganisms for screening for commercialisable bioactive molecules.

WAMSI, the Western Australian Marine Sciences Institution, has two main programmes, to establish a biodiversity management strategy for Western Australia, and to establish a state bioresources library with extracts made available for research and commercial investigation. WAMSI is organised in 6 nodes, of which Node 5 http://www.wamsi.org.au/category/region/research-biodiscovery is active in marine biodiscovery, biotechnology and aquaculture. WAMSI reports that 93 compounds have been isolated from indigenous organisms, including sponges, sea squirts and cyanobacteria.

Flinders University's Centre for Marine Bioproducts Development was established 2007 and works on bioprospecting, bioactives and algal biofuels http://www.flinders.edu.au/medicine/sites/marine-bioproducts/);
James Cook University's School of Tropical and Marine Biology carries out research work into ecology, microbial diversity, coral reef biology, algal physiology and biofuels potential and other areas relevant for marine biotechnology http://www.jcu.edu.au/mtb/index.htm;
The CMB (the University of New South Wales Centre for Marine Bio-Innovation http://www.cmb.unsw.edu.au) carries out research into biofouling and bioremediation, using ecological and microbial genomics, chemical ecology and microbial consortia.

SARDI (the South Australian Research and Development Agency http://www.sardi.sa.gov.au/) supports groups working on algal production systems, recently finding a new strain of *Nannochloropsis* with a high lipid and protein content for biofuels and biorefinery use, and aquaculture genetics and biotechnology.

Infrastructure

A range of CRCs (Cooperative Research Centres https://www.crc.gov.au/Information/default.aspx) was established in 1991 by the Australian Government, to facilitate innovation and knowledge transfer in different industry sectors. Of the 44 in existence in 2011-2012, the Australian Seafood CRC http://www.seafoodcrc.com/, established in 2007 with a grant of A$35.5M over 7 years, the Antarctic Climate and Ecosystems (ACE http://www.acecrc.org.au/) CRC, established in 1991 and renewed most recently in 2010 with a grant of A$18.7M over 4.5 years, and the Environmental Biotechnology CRC http://www.ebcrc.com.au/, established in 2010 with a grant of A$4M over 2 years, are active in relevant areas for marine biotechnology, including seafood genetics, Antarctic microbiology and bioremediation. The ACE CRC includes the Alfred Wegener Institute Germany as a core partner and collaborates with Belgium, Canada, China, France, Japan, New Zealand, UK and the USA. Other CRCs have a similarly wide range of international collaborations.

CSIRO manages the Australian National Algae Culture Collection http://www.marine.csiro.au/algaedb/default.htm. Griffith University maintains the Queensland Compound Library at the Eskitis Institute, where the Natural Product Discovery Unit was established in 1993 http://www.griffith.edu.au/science-aviation/eskitis-institute. The NQAIF, the North Queensland Algal

Identification/Culturing Facility, houses a tropical algal culture collection http://www.jcu.edu.au/mtb/research/laboratories/JCUDEV_016836.html. The Western Australia Museum houses the Western Australia Marine Bioresources Library, jointly established in 2009 by the WA Museum, WA Government, AIMS and the Western Australian Marine Sciences Institution.

Flinders University's CMBD has initiated an Australia-New Zealand Marine Biotechnology Network, with University of Waikato New Zealand and others http://www.flinders.edu.au/medicine/sites/marine-bioproducts/marine-biotech-network.cfm.

Public investment

Funds are available for academic research through the ARC (Australian Research Council http://www.arc.gov.au/) and for industry collaborations through AusIndustry grants http://www.ausindustry.gov.au/Pages/default.aspx.

WAMSI was established by co-funding of A$81M over 5 years, $21M from the Western Australia State Government via the Departments of Environment and Conservation, Fisheries and Industry and Resources, and $60M from a consortium including the Federal Government, AIMS, the Bureau of Meteorology, CSIRO, the National Research Flagship 'Wealth from Oceans', the Chemistry Centre, Curtin University of Technology, Edith Cowan University, Murdoch University, the University of WA, the WA Global Ocean Observing System, the WA Museum, the petroleum company Woodside, and the mining company BHP Billiton.

Private investment

Between 1993 and 2007, the pharmaceutical company AstraZeneca provided over A$100M to Griffith University, of which A$45M went into building the Natural Product Discovery Unit and the remainder into projects, screening and culture collections. In 2008, Griffith University's discovery partnership was re-established with Pfizer Inc, looking at new molecules for malaria and trypanosomiasis.

Marine Biotechnology Australia Pty Ltd is developing a potential treatment for herpes infections in humans derived from abalone haemolymph, supported by almost A$330,000 from AusIndustry; this has recently entered clinical trials, with funding from ARC. The company itself is investing over A$4.5M in the development. The enzyme company Cassa Bio-Tec has received over A$175,000 as a feasibility grant from a local council to remove beached seaweed and turn it into liquid fertiliser via enzymatic digestion.

Marinova Pty Ltd develops medical, cosmetic and nutraceutical uses of fucoidans from seaweed, including anti-viral and anti-cancer applications http://www.marinova.com.au/. AlgaeTec, based in the USA and Western Australia, has strategic partnerships with the Manildra Group, Lufthansa, Holcim Lanka Ltd and the Shandong Kerui Group Holding Ltd for development of algal biofuels and process systems http://algaetec.com.au/.

Trends

The trend is towards government investment in research translation into industry. The Industrial Transformation Research Program was established in 2011, with A$236M funding to help transfer innovation into industry, specifically focusing on strategic technologies with future economic impact, including engineering, materials science and nanotechnology, communications, chemical engineering and biotechnology http://www.arc.gov.au/pdf/ITRP%20-%20NOV%202011%20Revised%20on%205%20March.pdf. Up to 20 Industrial Transformation Research Hubs will be funded, initially for up to five years, allowing shorter- and longer-term projects with industry and economy focus. The ARC will put A$1M per year into each ITRH, to be matched by the industry partners. In addition, up to 50 Industrial Transformation Training Centres will be nominated over the next 5 years, giving up to 600 doctoral and postdoctoral researchers the opportunity to work with industry partners on research for specific industry needs. Each ITTC will receive up to $1 million per year for up to three years.

New Zealand

National strategy for biotechnology

The New Zealand Biotechnology Strategy was published in May 2003. In the 2000s, New Zealand put about 25% of its national R&D budget into biotechnology, almost NZ$200M pa. New Zealand Trade and Enterprise reported[33] in 2006 that it spent about NZ$11.5M on facilitating biotechnology development and industrial activity. NZTE's 10-year vision is to make New Zealand a world leader in niche biotechnology applications. It includes marine biotechnology within an environment and industry sub-sector of biotechnology.

National strategy for marine biotechnology

There is no specific national strategy but, in 2007, MoRST (The Ministry of Research, Science and Technology produced a roadmap for biotechnology research, which included marine biotechnology as a strategic component http://www.msi.govt.nz/assets/BiotechnologyRoadmap.pdf. Molecular aquaculture and marine bioactives were identified as the two major areas of strength in research. The roadmap noted that national needs for biosecurity, understanding of biodiversity, generation of new products including food, increased productivity and environmentally-sustainable industrial development all acted as triggers for government investment in or co-funding of marine bioresource research and development. It was recognised that there was a need to build research capacity and increase industry's ability to draw and apply research from this. Public investment in marine biotechnology, at c. $NZ4.5M in the 2004-2005 funding year, was about 2% of total biotechnology funding, 57% on use of genetics and biotechnology in aquaculture and 43% on bioactive extraction, characterisation and exploitation. Increased investment should go into basic and targeted research that would underpin future development, and helping links between industry and research.

The industry-led New Zealand Aquaculture Strategy was published in 2006, with a commitment to adoption of innovation and an economic drive towards a market target of over NZ$ 1B by 2025 http://www.seafoodnewzealand.org.nz/fileadmin/documents/Publications/Aquaculture_Strategy.pdf. The Five-Year Action Plan for the Aquaculture Industry was published by the government in 2012 http://www.fish.govt.nz/en-nz/Aquaculture/Aquaculture+strategy/default.htm. Although neither document refers to biotechnology, using 'innovation' or 'industry-led innovation' instead, funding rounds since adoption of the strategy have included aquaculture biotechnology.

Programmes

It is not clear whether there are any coordinated marine biotechnology programmes in place.

Centres of marine biotechnology research

NIWA (the National Institute of Water and Atmospheric Research http://www.niwa.co.nz/about-niwa/our-company) works in marine biodiversity and aquaculture, and bio-oil from algae, but has reduced its activities in marine biotechnology in recent years. The Australia New Zealand Biotechnology Partnership Fund has supported one project on a small-scale, to facilitate links in the area of natural bioactives, including marine-origin, managed by NIWA http://www.nzte.govt.nz/find-funding-assistance/australia-new-zealand-biotechnology-partnership-fund/pages/australia-new-zealand-biotechnology-partnership-fund.aspx. The institute has collaborated in the past with a New Zealand based sea food company Ngai Tahu Seafood, to explore the cosmetics market by isolating and identifying bioactives from sea food by-

[33] http://www.med.govt.nz/about-us/publications/publications-by-topic/evaluation-of-government-programmes/archive/overview.pdf

products and by-catch species, and with MalCorp Biodiscoveries on anti-inflammatory compounds for pharmaceuticals, but it isn't clear if these are current activities https://www.niwa.co.nz/fisheries/fau/no08-2003/natural-products-and-bioactives-research-at-niwa.

The Cawthron Institute has an aquatic biotechnology department involved in algal technologies, environmental monitoring and seafood safety http://www.cawthron.org.nz/aquatic-biotechnologies/overview.html. The Institute has significant experience with algal biology and a commercial algal production system for its shellfish hatchery, and is also involved in developing and commercially-exploiting its discoveries. In the microalgal field, the Cawthron has recently installed a 17-vessel automated photobioreactor system, which uses an innovative growth programme with multivariant analysis and control, to simulate as near-industrial conditions as possible and optimise algal performance.

The University of Waikato collaborates with the USA National Cancer Institute on marine bioactives and is a partner in an EU-funded marine bioactives project PharmaSea. Current activities include agrochemical applications of marine bioactives and biotechnology for aquaculture. Relevant departments include the Environmental Research Institute http://www.waikato.ac.nz/eri/about, Biological Sciences http://sci.waikato.ac.nz/about-us/biological-sciences/our-research and the Coastal Marine Group http://sci.waikato.ac.nz/research/centres-and-units/cmg/vision.

Infrastructures

The University of Canterbury's national marine bioresource collection was destroyed in the Christchurch earthquakes of 2011; the University of Waikato is maintaining this as a catalogue collection of recorded location information for the collection whilst a programme of re-sampling is to take place.

The Cawthron Institute manages what is effectively the national collection of micro-algae and cyanobacteria http://www.cawthron.org.nz/aquatic-biotechnologies/micro-algae-culture-collection.html. This is supported by state-of-the-art cryopreservation technology and contains many unique species, including those from unique environments around New Zealand, the Pacific and Antarctica.

Pacific Islands

The University of Aberdeen UK conducts bioprospecting activities in **Fiji**. Fiji's University of the South Pacific http://research.usp.ac.fj/index.php?id=home developed a Biodiversity access and benefit-sharing policy with SmithKline Beecham (now Glaxo SmithKline) and the Fijian Affairs and Fisheries Department. Note that Fiji possesses the 3rd longest reef in world, Cakaulevu.

Guam has been a site for marine natural products discovery for the Smithsonian Marine Station, Florida. The University of Guam's Marine Station is active in chemical ecology, reef management, coral biology and marine life systematics http://www.guammarinelab.com/research.html. The University is also a partner in the US NOAA's Sea Grant Program.

More information is needed on New Caledonia, Seychelles, Maldives, Samoa, Tahiti and French Polynesia.