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The development of marine biotechnology in Oman: Potential for capacity building through open innovation

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ABSTRACT

This study examines the current state of the art in the emerging and strategically important marine biotechnology sector in Oman, which has a long coastline, rich marine heritage and strong fishing industry. In a knowledge-based economy, the ability to innovate is a key factor for increasing organisational competitiveness and this may be achieved using open innovation. This is the use by firms of external knowledge, ideas and technology to innovate. In this study, the extent of open innovation in Omani marine bioindustry companies has been studied by examining data from the top sixteen companies ranked by number of employees. The results indicate that the extent of openness in these companies is higher towards market side activities. In addition, the use of open innovation to increase collaboration between companies, Universities and government research institutes needs to be significantly strengthened.

1. Introduction

Oman's economy is mainly based on revenues from oil and gas, which accounts for about 86% of government income [1] although economic diversification efforts by the government continue. It is therefore important to explore more dynamic and alternative economic activities in order to reduce dependency on fossil fuels [2]. Resource driven economies like Oman's should adopt dynamic and innovative economic strategies to increase their competition in the global economy [3]. The development of Oman's agriculture and fisheries sectors is one of the main priorities of the current five year development plan [4]. Examining alternative sectors that can reduce dependence on vulnerable areas such as declining fishing, to potentially more resilient sectors including marine biotechnology can offer a new competitive dimension to a country's portfolio of economic investment. High technology rich industries can make increasingly important contributions to sustainable economic growth as well as the generation of new jobs [5]. Globally, marine biotechnology plays an important role in meeting societal challenges and in supporting economic growth by applying recent advances in marine science and technology [6,7].

The marine ecosystem of Oman is characterised by great productivity and biodiversity exemplified by its coral reefs [8,9] and high fish diversity [10]. There are also many species of unique and diverse marine microalgae, diatoms, sponges, corals and invertebrates. Marine microbial diversity also represents an important biotechnological resource [11]. Many of Oman's marine resources have so far not been intensively investigated for their biotechnological potential.

Marine biotechnology can be defined as the use of marine biological resources as the target or source of biotechnological applications. This includes marine organisms, or parts thereof, used as feedstock, for example as food, fuel, materials or bioactive compounds [6]. Furthermore, the term “marine biotechnology” has been used widely in the international literature to also embrace fisheries activities and fish processing [12]. This study focuses on the traditional forms of marine biotechnology such as fish and seafood production and processing [13]. It will also establish a baseline for the measurement of marine biotechnology progress in Oman.

The aim of this study is to provide an overview of current marine bioindustry activities in Oman; to collect empirical data on production and innovation activities of key companies and to survey support organisations which could help bring about more directed and deliberate uptake of open innovation strategies. This will also provide a stronger context – specific background for marine policy makers to aid in increasing the development and sustainability of this sector by enhancing its competitiveness. Here we define marine

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bioindustries as companies which are active in selling products/processes based on marine organisms.

2. Open innovation

Both academic and business communities have shown significant interest in open innovation which is often a key management priority [14–16]. The concept of open innovation is built upon early Schumpeterian perspectives of the role of innovation in increasing economic competitiveness and his emphasis on the process of 'creative destruction' [17]. It is also built upon the earlier work by von Hippel about the importance of collaboration with users [18–20], suppliers and other external organisations [21] as sources for innovation. Related to this, scholars of innovation have also studied the role of a company's investment in R&D and its role in the generation of new knowledge [22].

Open innovation can be defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" [15]. It can be divided into two dimensions, inbound and outbound open innovation. This study is focussed on inbound open innovation which is defined as the internal use of external knowledge, while outbound open innovation refers to external exploitation of knowledge internal to the firm [23]. There are many benefits of an open innovation strategy which include the use of complementary resources through external collaboration, thus potentially increasing the company's scientific and technological knowledge and information [24]. External sourcing of technology can enable companies to build novel competencies that would be difficult to achieve using only internal competencies. The commercialisation capability of companies can also be enhanced by collaborating with universities, investing in research and development and external technology sourcing [25]. Inbound open innovation can be measured by using two dimensions – breadth and depth [26]. These terms have also been used to describe the two variables of a network for promoting innovation [27]. Breadth describes the number for different types of external partners or information sources involved in the innovation process. This can include suppliers, customers, competitors, consultants, research institutes and universities [28]. The depth dimension of innovation networks is focused on the extent to which deep integration between the firm and its external partner exists.

Open innovation can play an important role in helping companies to overcome significant constraints such as the availability of resources for research and development, and the provision of new technological capabilities. Internationally, successful marine biotechnology companies are characterised by significant collaboration with R&D institutes. There is an increased need for marine biotechnology firms to interact more widely with different sources of external knowledge, including, customers, end users and suppliers [29,30]. Open innovation has the potential to address these challenges and constraints [31–33].

Open innovation practices have been regarded as successful, primarily in industries such as biotechnology [23,25] a sector characterised by the need to use advanced, complex and often new technologies and to undertake extensive inter-organisational collaboration. Academic research on the implementation of open innovation within biotechnology companies has recently increased. For example, open innovation and the drug discovery and development process [34], and for increasing knowledge in the pharmaceutical industry [35]. Bio-pharmaceutical firms use open innovation practices such as licensing agreements, non-equity alliances, and supply/provision of technical and scientific services to acquire new or improved technologies and new knowledge [27]. Other authors [36] study open innovation to capture the full benefit of an external value chain in biotechnology or to explain a company's innovation performance [29]. In addition, it has been shown that internal learning and technology innovation capabilities also increase with the adoption of open innovation [37].

Innovation is widely considered to be a key driver for the development of a knowledge based economy. Recent research emphasises the role of a knowledge economy in increasing the sustainable competitive advantage and supporting growth [38,39]. Progress that countries make in innovation is also an indication of their increasing economic competitiveness and it also provides possible pathways to enhance the overall national innovation performance [40].

International rankings of innovation are increasingly being used as a measure of the ability of a nation to sustain productivity, growth and competitiveness for the longer term and to identify new national innovation strategies [41]. National innovation performance is important for Oman in its current stage of development, as it moves towards an innovation driven economy [42] therefore a current assessment of Oman's national innovation performance is important to allow monitoring of the effects of any measures or policies designed to enhance innovation. One of the key elements in strengthening national innovation performance is the quality of individual company's operations and strategies. In this study, the adoption of open innovation strategies by marine bioindustry companies in Oman and its impact on their growth and competitiveness was investigated.

2.1. Current assessment of innovation at the national level

In order to manage an innovation strategy on a national level and measure success of funded policies, growing attention is being paid to a number of innovation indices [43]. In this study, two global rankings were used to examine the performance of Oman in an international context. The first one is Global Competitiveness Index (GCI) which is published annually by the World Economic Forum (WEF) and the second one is the Global Innovation Index (GII) by The Business School of the World (INSEAD) in the collaboration of other agencies such as the World Intellectual Property Organisation (WIPO).

2.1.1. Global competitiveness index (GCI)

The World Economic Forum (WEF) is a non-profit, independent international organisation based in Geneva. Founded by Klaus Schwab, in 1971 [44] its main objective is to improve the state of the world by engaging academia, business and governments to shape the global, regional and industrial activities. In 2004, Professor Xavier Sala-i-Martin created a Global Competitiveness Index (GCI) for the first time, which measures national competitiveness by including both macroeconomic variables and microeconomic elements and it has been published yearly since then [45]. Competitiveness is defined as the set of institutions, policies, and factors that determine the level of productivity of a country. GCI measures the different determinants of competitiveness which is considered complex and open-ended by providing a weighted average for many different components of these determinants. These components are grouped into the 12 'pillars of competitiveness'. The pillars are organised into three sub-indexes: basic requirements, efficiency enhancers and innovation and sophistication factors, and each category one is critical to a particular stage of a nation's economic development Table 1.

The focus in this study is on the final data set of the pillars which includes the eleventh pillar 'business sophistication' and the twelfth pillar 'innovation'. Business sophistication is considered an essential factor in enhancing national competitiveness. It is related to higher efficiency in the production of goods and services which leads to an increase in productivity. It is concerned with, the quality of the country's overall business networks and

Table 1
Global competitive index (GCI).

	Sub-indexes	Pillars
1	Basic requirements	1. Institutions 2. Infrastructures 3. Macro-economy 4. Health and primary education
2	Efficiency enhancers	5. Higher education and training 6. Goods market efficiency 7. Labour market efficiency
3	Innovation and sophistication	11. Business sophistication 12. Innovation

Table 2
Global innovation index (GII).

	Innovation factors	Pillars
1	Innovation in-put sub-index	1. Institutions 2. Human capital and research 3. Infrastructure 4. Market sophistication 5. Business sophistication
2	Innovation out-put sub-index	6. Knowledge and technology outputs 7. Creative outputs

also the quality of individual firm operations and strategies. Network quality can be measured by the quantity and quality of local suppliers and the extent of their interaction with companies in geographically proximate area (clusters). While the quality of operations can be measured by the extent of advanced operations such as production process sophistication and extent of marketing.

The Innovation pillar is important for competitiveness and is measured by examining the amount of investment in research and development, especially by the private sector. The number of high quality scientific research institutions that can generate the basic knowledge needed to build the new technologies is also is an important attribute. In addition, the extent of collaboration in research and technological developments between universities and industry, as well as the protection of intellectual property, also form important components of the innovation pillar.

2.1.2. Global innovation index (GII)

The global innovation index is published by Cornell University, INSEAD and the World Intellectual Property Organisation (WIPO) a specialised agency of the United Nations [46]. It has been published for the last six years. It ranks 142 economies by their innovation capabilities and measures innovation using a range of methodologies. The GII helps to evaluate national innovation performance and its related policies for different countries. It is divided into two sub-indices—the Innovation Input Sub-Index and the Innovation Output Sub-Index—each built around pillars Table 2. For the Innovation Input Sub- Index has five input pillars to capture elements of the national economy that enables innovative activities: (1) Institutions, (2) Human capital and research, (3) Infrastructure, (4) Market sophistication, and (5) Business sophistication. While for the Innovation Output Sub- Index there are two pillars: (6) Knowledge and technology outputs and (7) Creative outputs. The overall GII score is the simple average of the input and output Sub-Indices. Each pillar is divided into three sub-pillars and each sub-pillar is composed of individual indicators, for a total of 84 indicators. In this study the focus is on a specific technology sector (marine bioindustry) and understanding its innovation performance against this national background.

3. The marine bioindustry sector of Oman

The geographical position of the Sultanate of Oman which occupies the South East corner of the Arabian Peninsula, bordering three marine regions: the Persian Gulf, the Gulf of Oman and the Arabian Sea provides access to marine ecosystems with high biodiversity including coral reefs and thus acts as an important source for marine resources used in products and services. It has a coastline of almost 3165 km in length, from the Strait of Hormuz in the North to the borders of the Republic of Yemen in the South-West [47] and is home to many coastal communities where fishery dependent livelihoods and sea trade are important. Oman also has a long history of fishing, which remains the second most important national economic activity after oil and gas [48]. The maritime heritage of Oman is also well known, with sea trade taking place with Africa, India and the far east for thousands of years [49]. Oman remains dependent on fisheries and agriculture as key economic sectors supporting employment and underpinning food security. In 2007, The Ministry of Agriculture and Fisheries Wealth, recognised the vulnerability of fisheries in providing employment and food security, thereafter developing a national strategic plan for the development of sustainable aquaculture which is now expanding [50]. The goals of the Omani aquaculture sector are to contribute to food security, help build self-sufficiency satisfy growing demand for fish and reduce negative fishing impacts on wild capture fisheries. One approach was through the production of saline-tolerant tilapia in artificial impoundments in coastal areas which gained interest among some fish farmers. Other types of fish farming, for example production of the Nile tilapia (*Oreochromis niloticus*) is taking place inland. About ten companies have recently (January 2015) received government approval for aquaculture activities in Oman and this number is set to grow in the coming years (Ministry of Agriculture and Fisheries Wealth, personal communication).

An important biophysical characteristic of the Omani coast is coastal upwelling [51] which supports high productivity in coastal areas which in turn have promoted high biodiversity and rich marine capture fisheries sector. The upwelling of the North West Indian Ocean occurs seasonally in response to the monsoonal wind regime and is considered to be one of the most intensive areas of upwelling in the world. There are a number of important hot spots of marine diversity which include coral reef habitats on the Dhofar coast in the South and the Hellaniyat Islands [52]. These are potential areas for sampling of novel marine organisms with the potential to support the development of marine biotechnology products. Thus reconciling the needs for future expansion of a sector with existing demands to maintain a sustainable marine ecosystem, requires consideration of the three pillars of sustainable development – economic, social and environmental, is an important consideration when building marine policy.

In addition to these diversity hotspots, there are many species of unique and diverse marine microalgae, diatoms, sponges, corals, fungi and invertebrates in Oman's coastal waters which are being investigated as future biotechnological projects. For example, five farinomalein derivatives including three new compounds were isolated from an unidentified endophytic fungus obtained from the inner tissue of healthy leaves of the mangrove plant *Avicennia marina* [53]. Another study reported the first reported species of bryozoan from the southern area of Oman [54]. Further work has been conducted on the extraction of κ-carrageenan from the red seaweed (*Hypnea bryoides*) which is found in abundance in the Southern region of Oman has been targeted for expansion due to its commercial value [55]. In addition to these examples of research mainly within the University sector, on useful bioactive compounds, there is also a marine bioindustry sector, active in Oman today.

Table 3
Ranking of companies within the marine bio- industry sector in Oman (2013).

Rank	Company	Capital (OR)	Sales Turnover (OR) 2013	Year estab-lished	No. employees	Location	Marine bio-products
1	Oman Fisheries Co.	12.5 M	26 M	1989	450	Muscat	Fish and seafood production, processing and trading, new line for value added.
2	Dhofar Fisheries Industries Co	6.22 M	7.2 M	1997	108	Salalah	Canned Tuna and canned Sardines and added value products (canned tuna marinated in spices and vegetables).
3	AlJarjoor Establishment	300,000	4.5 M	1994	75	Muscat	Fish & seafood production, processing and trading.
4	Sea Pride	785,000	5.8 M	2013	70	Sur	Fish & seafood production, processing, trading and added value products.
5	Al-Ainkawi Enterprises Fisheries Division	1 M	2.5 M	1982	64	Muscat	Fish & seafood production, processing and trading.
6	Al-Marsa Fisheries	760,000	4 M	2006	50	Muscat	Fish & seafood production, processing and trading.
7	Bentout Seafood products	3 M	500–600,000	2006	38	Al-Duqum	Aquaculture (shrimps).
8	Al-Hamadi Fisheries Co.	553,000	1.5 M	1989	35	Muscat	Fish & seafood production, processing and trading.
9	Five Oceans Co.	150,000	800,000	2002	35	Bidbid	Fish & seafood production, processing and trading (newline of products).
10	Majan Import & Export Co. LLC	150,000	25,000	2013	30	Al-Khabourah,	Fish & seafood production, processing and trading.
11	Al-Moqala Establishment	125,000	1.8 M	1996	26	Sur	Fish & seafood production, processing and trading.
12	Rwad Al-Ibtikar	150,000	400,000	2007	25	Muscat	Fish & seafood production, processing and trading.
13	Pelagic Fisheries Trading	90,000	500,000	1992	22	Sur	Fish & seafood production, fish drying and salting and trading.
14	Al-Bahihi Fisheries Co	100,000	1.1 M	1997	20	Salalah	Fish & seafood production, fish drying and trading.
15	Asmak Al-Sharqyia	127,000	28,000	2010	17	Sur	Fish & seafood production, processing and trading.
16	Abu-AlawiTrading	60,400	249,129	1997	8	Salalah	Fish & seafood production, processing and trading.

Table 4
Emerging companies in marine biotechnology in Oman (2014).

No	Company Name	Location	Year Established	Marine Bio-products
1	Fish meal and Fish oil Co.	Jalan Bani bu Ali	2011	Fish meal and fish oil
2	Fish meal and Fish oil Co.	Sur	2014	Fish meal and fish oil
3	Knowledge for advanced technology	Sur	2014	Aquaculture
4	Arabic company for marine development	Jalan Bani Bu Hassan	2014	Aquaculture
5	Al-Jazeera for investment	Masirah	2014	Aquaculture
6	Atlas company	Jalan Bani Bu Ali	2014	Aquaculture
7	Al-Hasen for investment	Qurayat	2014	Aquaculture

The top sixteen companies in the marine bioindustry sector in Oman according to the number of employees is shown in Table 3. These companies mainly produce fish, seafood and marine added value products. The Oman Fisheries Company and Dhofar Fisheries Industries Company are ranked as the top two companies. In addition, there is a small and growing group of emerging companies in the area of fish meal, fish oil and aquaculture Table 4.

The marine biotechnology sector is strongly related to fish and fish farming in the following ways. First it is based on raw materials obtained from the sea or by-products from the fishing industry. Secondly, this sector is providing food ingredients and health related products to industry. The marine bioindustry companies that exist in Oman are currently most active in the areas of fishing and fish farming reflecting traditional dependency on these sectors and this is expected to continue. There are however a wave of smaller more high technology-based marine bioindustry companies emerging and it is essential that these companies are supported and encouraged to innovate to sustain grow. Fig. 1a and b compares the marine biotechnology sector between Oman and Norway. Norway was selected for comparison because of the following shared factors, first its economy has in the past been dependent oil and gas, but has diversified as oil production has been falling steadily since the 1990s [56], providing important lessons for Oman's diversification strategy. Second, like Oman, Norway has significant maritime and marine heritage linked to an extensive coastline access to a diverse and productive marine habitats [57]. Third, Norway has invested significantly in marine biotechnology, including aquaculture which is considered world leading [58]. Fig. 1 shows that Oman has more companies in the area of the fishing and fish products and fewer companies where products rely on more advanced technologies, for example, drug development, enzymes and biopolymers. On the other hand, Fig. 1b shows that for Norway, which has a more mature marine biotechnology sector, there is a greater number and proportion of high technology marine bioindustry companies. Two of these are traditional fisheries companies that have then evolved into more high technology marine biotechnology companies [30]. Similarly, this process is also starting in Oman. For example, Sea Pride LLC a traditional fish capture company is now gradually extending the technological levels of it product range by producing fish meal and fish oil. The adoption of an open innovation strategy by marine bioindustry firms in Oman, such as these, should allow their continued development.

Thus there is growing interest in studying open innovation as an approach to catalyse innovation driven economic development in the marine bioindustry sector in Oman. Although extensive research has been carried out on open innovation in western countries, there is very limited information on open innovation at the company level in the Arab World.

Oman would benefit from a specific focus on investment in innovation by increasing research funding and targeting investment to encourage open innovation including well established industries such as the fisheries sector. Marine biotechnology can then grow through capacity building in advanced life sciences research and technology. The increased use of open innovation in newer and rapidly growing sectors such as aquaculture, for example, is to be encouraged as this sector grows in the coming years.

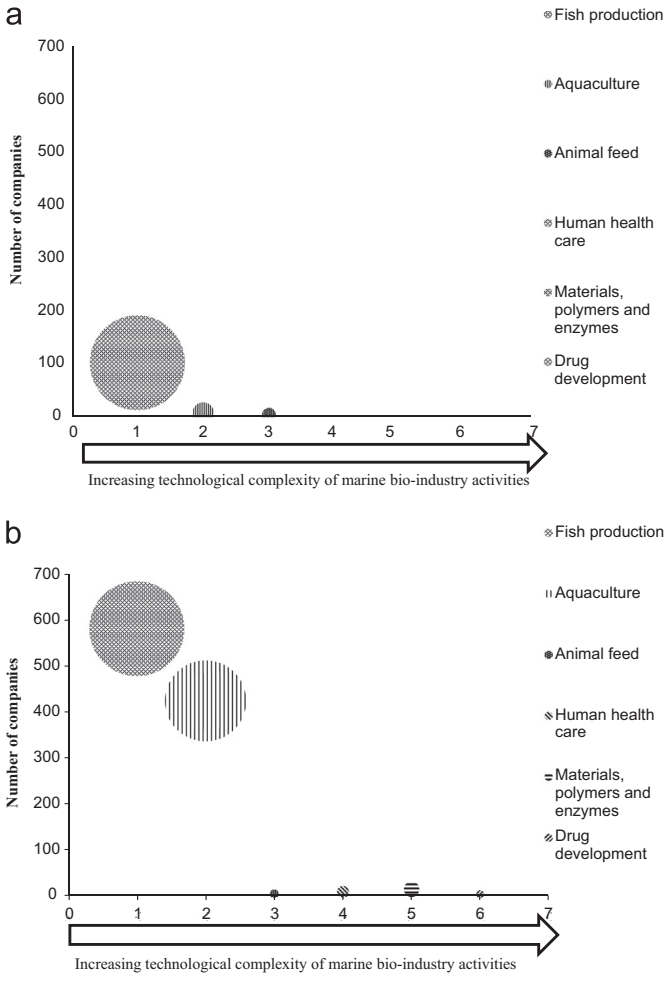

Fig. 1. Comparison of the marine biotechnology sector between (a) Oman and (b) Norway.

4. Methodology

Most empirical studies on the adoption of open innovation at the company level have focused on Europe and to some extent Asia because of the availability of large scale secondary data such as the Community Innovation Survey [59,60]. However, due to the lack of appropriate data available in Oman, this study relies on new empirical data collected from representatives of individual Omani marine bioindustry companies.

4.1. Open innovation in the marine bioindustry sector in Oman

4.1.1. Data and sampling

A desk-based review identified existing data on Omani marine bioindustry companies which included fish and seafood processing and aquaculture. Secondary data was collected from the Ministry of Commerce and Industry, which provides information on all registered companies. These data were validated using quality assurance numbers provided by the Ministry of Agriculture and Fisheries Wealth and using interviews with regional experts. A group of smaller more high tech marine bio-products companies were also identified – through face to face interviews with the head of department of quality assurance at the Ministry of Agriculture and Fisheries and Aquaculture centre, followed by interviews with the owners of these companies.

Semi-structured interviews ($n=11$) were conducted between April and September 2014 to collect data from 16 Omani marine bioindustry companies by interviewing either the owner of the company or the assistant manager dealing with development activities. Telephone interviews ($n=5$) were also used to increase the response rates and were conducted from April to December 2014. Interviews lasted 1–2 h and were focused on the history of the company, products, awareness of innovation, open innovation breadth and depth dimensions, R&D investments, markets, competitors, and collaboration with research institutes over the previous five years Tables 3–5.

Table 5
Breadth and depth parameters of open innovation activities of 16 Omani marine bioindustry companies.

Category of knowledge source	Knowledge source	Breadth – number of companies which use these sources	Depth – number of companies	
			Low	High
Market				
	Suppliers of equipment, materials, components, or software	16	1	15
	Clients or customers	16	1	15
	Competitors	13	8	5
	Consultants	8	5	3
	Commercial laboratories / R&D enterprises	2	1	1
Institutional				
	Universities or other higher education institutes	4	1	3
	Government research organisations	1	0	1
	Other public sector, e.g., business links, government offices	10	3	7
	Private research institutes	3	1	2
	Health and safety standards and regulations	14	1	13
Semi public				
	Professional conferences, meetings	14	2	12
	Fairs, exhibitions	16	5	11
	Internet	16	2	14
	Scientific Publications	6	3	0
	Technical / trade press, computer databases	8	3	5
	Trade associations	11	7	4

4.1.2. Measuring breadth and depth of openness

The extent of open innovation within a company as a whole can be evaluated by measuring the different activities which make up open innovation. In their developed construct, Laursen and Salter [26] developed the concept of breadth and depth to measure openness. While these measurement scales are used in studies which rely on existing data such as the CIS for example, there are other studies [61–63] that have adapted their scales for use with primary data sets.

Laursen and Salter's scale includes 16 external sources to represent the breadth parameter describing the different types of external knowledge Table 5. Laursen and Salter measure depth using a 0–3 Likert scale to describe how deeply companies draw ideas for innovation from each of the 16 information sources. The same approach was used here. More specifically, breadth of open innovation was measured by calculating how many of the 16 external knowledge sources are integrated into a company's innovation process and the depth of open innovation was measured by the number of these sources that are deeply integrated into company's innovation process.

4.2. Knowledge generation in marine biotechnology in Oman

Knowledge generation is defined as the publication of peer reviewed scientific papers as an indicator of research output performance. Secondary data on research projects were collected from three main sources, the university sector, private companies and governmental ministries. Different social science survey methods were used to collect empirical data from interviews including telephone surveys with researchers and research institutes supported by an analysis of data obtained from desk reviews of secondary data as shown in Table 6.

4.3. Policy programs affecting marine biotechnology in Oman

The findings regarding marine biotechnology and policies which are likely to support open innovation were collected from sourcing and synthesising the relevant institutions and organisations that had these in place Table 7.

5. Results

5.1. Open innovation

To assess the extent of open innovation taking place in Omani marine biotechnology companies, they were asked to identify the different types of external knowledge sources used (breadth), and to estimate the importance of each source (depth) on a scale from 0 to 3. The questionnaire contained a list of three different categories of knowledge sources classified as market-based, institutional-based and semi-public Table 5. For breadth dimension, the three external knowledge sources used most frequently from the market-based

Table 6
Knowledge generation in applied marine biology in Oman (2014).

	Organisation	R&D Programs	Main focus
	Universities		
1	Sultan Qaboos University (SQU)	Oman Biofouling research	Formation and diversity of biofouling communities Effectiveness of current antifouling methods Identifying biofouling species causing major industrial problems
		Economic, social and environmental impacts of marine biofouling in the Sultanate of Oman	Biofouling in Oman waters Cost effective ways to prevent biofouling Novel antifouling defences using nano- and fouling release coatings
		Bioremediation of oil-polluted ecosystems in the Sultanate of Oman	Bioremediation of oil-polluted areas in Oman Bioactive compounds that enhance oil bioremediation
		Anti-quorum sensing and anti-cancer compounds	Quorum inhibitors from marine organisms Screening marine natural compounds for anti-cancer properties
	The Centre of Excellence in Marine Biotechnology	Multi-disciplinary marine biotechnology research programs	Making optimal use of Omani marine resources Internal and external research funding for multi-disciplinary marine biotechnology research programs
2	University of Nizwa (UoN)		
	(UoN) Chair of Oman's medicinal plants and marine natural products	Discovery of Lead Compounds from Omani Seaweeds and Algal Blooms	Isolation, structure assignment using NMR Synthesis of marine natural products with activity against cancer, malaria, tuberculosis and neurological disorders etc
	Ministries		
3	Ministry of Agriculture and Fisheries, Aquaculture Research Centre	Breeding of Native Red Sea Bream	Breeding, larval rearing and grow-out of red sea bream under Omani conditions
	Ministry of Agriculture and Fisheries, Aquaculture Research Centre	Atlas of Suitable Sites for Aquaculture	Evaluated specific sites for Aquaculture The suitability for commercial aquaculture operations An Atlas of the entire coastline produce using satellite input
	Ministry of Agriculture and Fisheries, Aquaculture Research Centre	Diversity, Stocks and Aquaculture Potential of Sea Cucumber, Holothuria Scabra	Applying sea cucumber culture technology as a means of enhancing natural stocks
	Ministry of Agriculture and Fisheries, Fish Quality and Control Centre	Quality control and safety	Quality control and safety of marine products and fishing industries Evaluation of commercial fishing vessels to ensure compliance with quality control systems adopted
	Ministry of Agriculture and Fisheries, Marine Science and Fisheries Centre	Species breeding seasons	Identifying species breeding seasons Accessing the current inventory Accessing the status of fisheries to know whether there's overfishing or not Identifying maintenance and conservation models and development of aquaculture
4	Ministry of Higher Education, College of Applied Sciences Sur		Applied Biotechnology programme.

Table 7
Policy programs related to marine biotechnology in Oman.

	Policy Programme	Organisation	Main focus
1	The Open Research Grant programme	The Research Council (TRC)	It aims at enhancing research capacity in the Sultanate of Oman by allocating small to mid-sized research grants for short and mid-term projects
2	Animal and Plant Genetic Resources Centre	The Research Council (TRC)	Oman's collaborative organisation for advancing sustainable use of animal and plant genetic resources through education, research and innovation
3	Industrial Innovation Centre (IIC)	The Research Council (TRC)	Identify research & development (R&D) areas in Omani industrial companies and create collaborative linkages between industries and research institutions.
4	Technology Transfer Office/ Agents	Industrial Innovation Centre (IIC)	Working with commercialisation of research based knowledge from the university and also to help industry find strategies for how to exploit it

sources are clients or customers, suppliers and competitors. The other most frequently used source is 'Fairs and exhibitions'. This shows that interactions with external sources were most dominant on the market side. The important role played by semi-public sources can be explained by taking into account their greater accessibility and lower cost.

With regard to institutional type, the most common source of knowledge used by companies is 'safety standards and regulations' (institutional sources). On the other hand, there is a quite moderate collaboration between companies and other public sector bodies for example as business links government offices. Notably, collaboration with universities and governmental research institutes was found to be low. Similarly, for the depth parameter the companies intensively used customers, suppliers and 'Health, safety standards and regulations' as source of knowledge in their innovation process.

5.2. Knowledge generation in the marine biotechnology sector

A broad analysis of knowledge generation in applied marine biology in Oman is shown in Table 6. Knowledge generation mainly comes from two types of institutes: universities and public sector laboratories or research centres. The main component of knowledge generation in marine biotechnology in Oman includes the education and research programmes. Sultan Qaboos University (SQU) and the Ministry of Agriculture and Fisheries represent the main educational and research organisations in the sector Table 6. The most important research programmes in marine biotechnology were shown to be mainly in SQU and the Ministry of Agriculture and Fisheries. The main research focus areas in SQU's College of Agriculture and Marine Sciences are bio-fouling and quorum sensing inhibition. The Centre of Excellence in Marine Biotechnology at SQU was established to develop capacity building in marine biotechnology in Oman. This centre recently organised the first GCC Marine Biotechnology conference [64]. There are three main government research activities in Oman: Aquaculture Research Centre, Fish Quality and Control Centre and Marine Science and Fisheries Centre. Additionally there are a number of new Universities in Oman, such as University of Nizwa, which has a centre focussed on the chemistry of marine natural products and plant metabolites (Prof A. Al-Harrasi personal communication).

5.3. Contributions to policy in the marine biotechnology sector

The advancement of marine biotechnology also depends on the formulation of appropriate policy [65].The findings identified that in order to facilitate the development of a more knowledge based industry, public support for R&D, through the Research Council of Oman, has been organised in a programme consisting of six main sectors. Marine science is one of the areas under the environmental and biological resources sector. As shown in Table 7, the establishment of an Industrial Innovation Centre (IIC) is also placed to catalyse and support linkages between academia and industry. The IIC also supports industrial development and

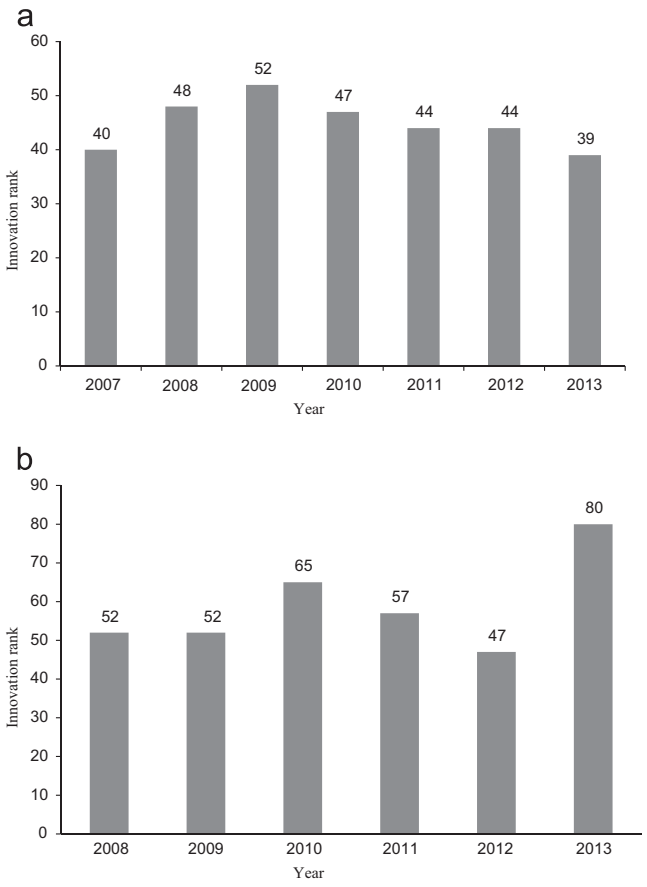

Fig. 2. Innovation rank of Oman with time using (a) the Global Competitive Index and (b) the Global Innovation Index.

stimulates technology transfer and the commercialisation of research. Studies have shown that national policies do influence the performance of national technological innovation systems [66]. Therefore, the national innovation ranking for Oman has been applied in analyses for the following Section.

5.4. World rankings

The data published on the innovation performance of Oman in the Global Competitiveness Index was first published in 2007 and for the global innovation index in 2008. The overall innovation performance for Oman is presented during the period 2007–2013 in Fig. 2. Innovation performance was determined from the global competitive index Fig. 2 showed yearly trends with a gradual increase of position from 2010 to 2013. Table 8 also presents the innovation ranking of Oman, which was positioned 39th in the world when using the global competitive index (GCI), compared to 44th and 47th previously. Table 8 also shows that the report

Table 8
Comparison of Oman's innovation ranking with other countries in GCI (2013–2014).

Country	Innovation and Business sophistication factor	
	Score	Rank
Switzerland	5.72	1
US	5.43	6
UK	5.15	10
Qatar	5.08	14
Norway	5.07	16
France	4.84	18
UAE	4.67	24
Saudi Arabia	4.33	29
China	4.10	34
Oman	**4.05**	**39**
Jordan	3.87	51
Bahrain	3.71	59
Tunisia	3.47	79
Lebanon	3.40	90
Morocco	3.34	100
Egypt	3.31	104
Libya	2.71	141
Algeria	2.63	143

placed Switzerland at the top of the rankings and Qatar best placed for Middle East and North Africa (MENA) nations.

On the other hand the global innovation index shows Oman ranked 80th in 2013, losing 33 places from 2012 ranking of 47 as shown in Fig. 2b. Since it has been suggested that Oman is one of the countries whose ranking has been most affected by the new methodology adopted by the Global Innovation Index (GII) in 2013 [46]. The introduction of new indicators with the greater weightings on innovation outputs has affected Oman's ranking significantly. This demonstrates that Oman is facing a significant challenge to increase its national innovation performance, in competition with other nations which is discussed in the next section.

6. Discussion

The future economy of Oman is expected to gradually shift away from its current heavy dependence on oil and gas towards a more diversified economy. In an effort to provide alternative employment and income generation opportunities for a growing population, it is recognised that a knowledge based economy built on innovation is vital. One sector which is expected to grow is the applied use of marine bioresources or marine biotechnology. The findings of this study therefore represent a starting point with regard to how the adoption of open innovation by marine bioindustry companies in Oman may be a relevant tool in encouraging innovation in this sector.

In the first part of this study we investigated the current level of open innovation adoption in the marine bioindustry sector in Oman. This sector consists mainly of traditional fish processing companies as well as emerging marine biotechnology companies. The products of fish processing companies are divided into different types; frozen products like fish, seafood products, and traditional products such as dried and salted fish and canned tuna. More recently attention has focused on fish processing and the greater use of technology driven processing to provide more added value [67–69]. For example, the trend towards marine bio-compounds and aquaculture activities has grown within the Icelandic economy due to its link with the traditional fisheries sector and extensive interactions between companies [70]. In Oman, there are a number of companies that have emerged within the marine bioindustry sector that can provide increased economic opportunities. In this study, the complexity of the Oman marine biotechnology sector with the more developed Norwegian sector were also compared [65,71].

Both countries are considered important fish and fish products exporter nations with Norway being the world's second largest exporter of fish and fish products by value. Similarly Oman is one of the important Arab nations in fish exporting and a net exporter of fisheries products in the Gulf Co-operation Council (GCC) region [72]. However, Norway has a growing and well developed aquaculture industry, which is larger than that in Oman [30] which is still in the early stages of development. One reason for this is the focus in Norway on fish health and the provision of high quality fish food production and rearing knowhow [71]. Norway has strengthened its aquaculture industry through the formation of institutional as well as regulatory frameworks, building supporting organisations such as technology transfer organisations and R&D institutions and establishing private technology suppliers with specific expertise. Similarly, Oman has also established a regulatory framework (investment guidelines and a one stop shop for licensing) [73] and R&D institutes such as the Aquaculture Research Centre to support this sector. However, there is a lack of private technology suppliers with specific expertise.

The Norwegian sector is characterised by a higher number of companies carrying out advanced marine biotechnology compared to Oman, which has mainly fish and fish farming companies. Norway has supported the development of advanced marine biotechnology in the city region of Tromso in Northern Norway for example by increasing the number of spin-off companies from universities. There are six marine biotechnology companies in Tromso that have been established by the university [74]. These companies were based on marine biotechnology knowledge from Tromso University and the compnaies have also established regional and international partnerships, to gain access to additional resources such as finance, laboratory facilities and marketing which also help in their long term survival [12]. On the other hand, there are no spin off based on marine biotechnology companies in Oman at present, although capacity is building at Sultan Qaboos University and University of Nizwa Table 6.

In general there are three main lessons to be learned from the marine biotechnology sector in Norway; first, the importance of development of marine biotechnology activities that can support the aquaculture industry. In particular, the animal feed industry and this has already started in Oman. Second, the development of private technology suppliers with specific expertise that can support its development. Third, the creation of spin off companies from academia focussed on specific areas such as human food and health care.

There is an increasing interest in studying different innovation processes that can increase the innovation performance of a company. Inbound open innovation for example depends on the use of external sources of knowledge and information available in both the industry and institutional sub-systems which can be found across a firms' boundaries. The key companies in marine bioindustry sector in Oman have been studied and the first systematic synthesis has been provided to describe the breadth and depth of the extent open innovation of these companies. The most frequent source of new knowledge (breadth) and the most intensive source (depth) used by companies has been identified as following customers, suppliers, competitors and health and safety. This is consistent with innovation system approach which emphasises the importance of interactions among actors in the market side [75]. As might be expected, the innovation activities of Oman marine bioindustry companies are strongly determined by relations between themselves and their suppliers and customers and emphasis of market side interactions has also been observed by Belussi et al. [29], in the life sciences sector in Italy [29]. Additional studies in The Netherlands, on the role of networks in the innovative activities within the Agri-food industry

which includes fish processing indicates that successful innovative companies also have strong market side collaboration [76]. Traditional marine biotechnology activities such as fish processing is characterised by a supply demand and the high pressure of buyers in which customers act as a driver for innovation [31]. Other studies have also supported the collaboration with the market side sector by creating alliances with market side partners which can give strong initial performance for biotechnology companies [77]. This type of collaboration allows companies to obtain complementary assets through market exchange which is more efficient than acquiring them through internal transactions [78]. However, a balance between collaboration with market side partners and R&D partners is needed for further improvement of the innovation performance of these companies.

Traditional activities like fish processing are characterised by low intensity of research and development (R&D) [79]. On the other hand, the emerging industries towards more high tech industry are changing the research landscape which will create a real need to enhance the role of research and development (R&D) and collaboration [80]. The analysis of R&D collaborations in this study has shown that it is quite low and leaves room for improvement. Some previous empirical studies indicates that research collaborations between companies and governmental research institutes or universities in emerging food biotechnology companies is playing a prominent role in innovation process of these companies [81,82]. Contractual and non-contractual forms of collaboration between biotechnology companies and government research institutes or universities can occur [83]. Studies also showed that innovation performance of biotechnology companies can be increased through international collaboration with universities particularly for biotechnology development in developing countries [84]. The OECD also indicated that biotechnology SMEs in developing countries which have an emerging biotechnology sector should have access to different resources from developed countries [85]. Seen in this light, it is noteworthy that in most companies the collaboration with R&D institutes needs further improvement to enhance development.

In Oman, a knowledge structure has been established and is growing. Research groups have been created in marine biotechnology, for example, there is a research group at the University of Nizwa focusing on the discovery of lead compounds from Omani seaweeds and algae to be used for medicinal purposes. The biotechnological potential of marine seaweeds and algae is well recognised for example, the anti cancer activities of seaweed extracts on breast cancer and potential antioxidative activities of enzymatic extracts from of brown seaweeds [86,87]. Other research programmes in Oman focus on investigating the possibility of breeding and rearing native red sea bream [88] also of international interest [89]. In addition, the different education and R&D programmes such as those at Sultan Qaboos University, the Ministry of Higher Education and the research institutions of the Ministry of Agricultural and Fisheries Wealth are providing an important science base for the future development of the marine sector and its related areas. Universities are playing increasingly major roles in developing fundamental knowledge, innovation and economic growth [90].

Table 7 shows that one of the main public R&D funding programmes in Oman is awarded by The Research Council (TRC). The public funding programmes play important roles in the development of institutional and knowledge based infrastructure needed for the development of marine biotechnology sector. Within the marine biotechnology sector internationally, a number of countries have developed policies to aid its development. Ireland has set integrated policies for the development of its maritime sector which includes marine biotechnology. It has set itself the target by 2020 of becoming an international centre for research into ocean related technology [91,92]. Through industrial collaboration, Norway has also established an industrial R&D programme for marine biotechnology in Northern Norway (MABIT) [93]. This programme has a strong focus on applied research and the industrial application of marine biotechnology. Its aim is to increase 'added value' in the fishery, aquaculture and biotechnological industries in Northern Norway. In total about 30 companies have been involved in this programme with total support funding of about 6 million euro. Another example where policy programmes are used to support open innovation is in The Netherlands, where the government has initiated a programme based on using an open innovation approach to help the development of SMEs using an "Innovation voucher programme" [94]. The findings of this study help make a case for policy makers and companies in Oman to seek opportunities for increasing collaboration between different key players to enhance knowledge flow, and subsequent successful innovative developments. These programmes enhance the development of innovation within the marine biotechnology sector and this can subsequently also impact the dynamics of the national innovation system [66].

The national innovation performance of Oman in recent years has been increasing. However in comparison to many other countries in the region Oman is still lagging behind in its innovation rank. The dynamics of the national innovation system can be impacted by the improving capacity of national science and technology performance. In Taiwan for example, the development of biotechnology has positively impacted national innovation networks and shifted to the 'knowledge creation power' phase [66,95,96].

7. Conclusions

The application of marine biological resources from traditional and emerging marine bio-industry sectors such as fisheries to aquaculture, and drug discovery to more advanced applications is increasingly being recognised as a globally significant economic growth sector, commonly termed marine biotechnology. The first baseline study of marine biotechnology activity in Oman is provided here by examining the current status of Omani companies which actively develop products from marine biological resources (marine bio-industries). In order to further understand how this sector can be strengthened, we studied the extent of Open Innovation in the identified companies. The results demonstrated that while open innovation is on-going and active for marketing activities, with respect to R&D, inbound open innovation between companies and government research institutes and Universities, needs to be significantly strengthened. These constraints can be overcome through company and government initiatives to stimulate greater open innovation activities focussed on developing successful applied marine bio processes. Lessons learned from the methods adopted in this empirical based research could be used to advance appropriate application of open innovation in developing the marine biotechnology sector in other countries around the world.

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