Chapter 3

Contributing to the bioeconomy: The economic potential of marine biotechnology

This chapter discusses existing and potential markets and other economic benefits to be realised through marine biotechnology. In the current economic situation, understanding the impact of investments and maximising returns on investment are more important than ever. This chapter therefore looks at existing measures and indicators for marine biotechnology and considers what further measures and indicators may be required.

Renewed interest in marine biotechnology has arisen in parallel with the birth and growth of the notion of the bioeconomy, the economic sectors that are based on bioscience and biotechnology innovation.[1] In 2009, the OECD's International Futures Programme undertook a project, The Bioeconomy to 2030, which examined the ways in which the bioeconomy is likely to create economic and social benefits for OECD and non-OECD countries.

Since that time, the term "bioeconomy" has become firmly entrenched in the lexicon of most OECD countries and has been taken up with different degrees of urgency. In 2009, Finland included a specific national bioeconomy strategy in its Council of State Natural Resources Strategy[2] and other Europeans countries (Denmark, Germany, Ireland and the Netherlands) also have national bioeconomy strategies. More recently, in February 2012, the European Commission announced a vision for the European Bioeconomy (European Commission, 2012). It estimated that the EU's bioeconomy sectors are worth EUR 2 trillion in annual turnover and account for more than 22 million jobs and approximately 9% of the workforce.

Outside Europe, Canada, the People's Republic of China and South Africa[3] either have or are planning their own ambitious strategies, and in April 2012 the United States published the US National Bioeconomy Blueprint.[4] This document recognises the bioeconomy as a political priority because of its tremendous potential for economic growth and social benefits. It considers that the bioeconomy will allow US citizens to live longer, healthier lives, reduce national dependence on oil, address key environmental challenges, transform manufacturing processes, and increase the productivity and scope of the agricultural sector while creating new jobs and industries.

Most of these bioeconomy strategies or visions include references to marine bioresources or marine biotechnology, and many of the opportunities identified and discussed in these documents and in the OECD's *Bioeconomy to 2030* (OECD, 2009a) have parallels in the field of marine biotechnology. For instance, food production and biofuels (agricultural biotechnology), development of new drugs (health biotechnology), of new materials (industrial biotechnology) and of bioremediation technologies (environmental biotechnology) are all potential sectors of application of marine biotechnology.

This indicates that marine biotechnology can make an important contribution to the bioeconomy through the development of innovative products and processes, the creation of jobs and the building or "greening" of a number of industries and sectors.

The market value of marine biotechnology

The global market for marine biotechnology products and processes is believed to offer a significant and growing economic opportunity. The widely cited Global Industry Analysts, Inc., estimated the global market for marine biotechnology at EUR 2.8 billion (2010 estimate), with a compound annual growth rate (CAGR) of 4-5% (or 10-12% under less conservative assumptions).[5] However the value of its contribution is difficult to quantify given the wide range of marine biotechnology applications and the difficulty of measuring and tracking these different markets. Marine biotechnology appears to differ from other biotechnologies in that it is defined in terms of its source (or target) material rather than the market it serves.

Nevertheless it is useful, and in many cases necessary, to quantify the market and market potential of marine biotechnology in order to attract investment and to guide policy development. However, the paucity of data and the fragmented markets only allow for estimating the value of a few markets. While this is a laborious and somewhat imprecise approach, it may help to illustrate the market potential of the field.

Pharmaceutical products

It is possible to quantify the market for some marine-sourced drugs and bioactive compounds because the industry is well established and data on commercialised products are publicly available. An early market success of marine biotechnology involved the extraction of the arabinosides Ara-A (Vidarabine®, Vidarabin®, Thilo®) and Ara-C (Cytarabine, Alexan®, Udicil®) from a sponge, *Cryptotethya crypta*, in the 1950s (Bergmann and Feeney, 1951). These compounds have anti-viral (Ara-A) and anti-leukemic (Ara-C) properties and an annual market of USD 50-100 million.[6]

The anti-inflammatory and analgesic pseudopterosins isolated from a Bahamian soft coral, *Pseudoterigorgia elisabethae*, are another useful example. These marine-derived compounds led to the development of bioproducts now used in skin care and cosmetics lines and are currently worth USD 3-4 million a year.[7]

Biotechnology

Several well-characterised bioactive compounds, such as shrimp alkaline phosphatase (SAP), isolated from organisms living in cold aquatic environments, and a thermostable DNA polymerase enzyme, isolated from the thermophilic bacterium *Thermus aquacticus* in hot springs, have found considerable commercial success in the biotechnology sector.

In 1985, Kary Mullis described how this thermostable DNA polymerase, known as *Taq* polymerase, could be used to amplify *in vitro* targeted DNA or RNA sequences rapidly using the polymerase chain reaction (PCR).[8] The Cetus Corporation patented the enzyme and associated technique and sold it to Hoffman-LaRoche for USD 300 million in 1991. PCR using *Taq* polymerase and other synthetic polymerases with similar properties is now used in biotechnology laboratories worldwide and represents a considerable market: sales of *Taq* DNA polymerase in Europe alone were USD 26 million in 1991 (Roberts, 1992) and had an initial estimated annual market of USD 50-100 million. The market for DNA polymerases is now believed to be in the order of USD 500 million a year.[9]

Fish and shellfish

The aquaculture industry is another market for which data exist. It is, however, difficult to assess the contribution of marine biotechnology to total market value. Taking commercial salmon production[10] as an example, the worldwide production of farmed Atlantic salmon exceeded 1.4 million tonnes in 2009 for a market value of USD 6.4 billion[11] (FAO, 2011). However, even though molecular aquaculture[12] is a significant part of salmonid aquaculture in most regions, the contribution of marine biotechnology to production and market value is not known. Also not captured in this market evaluation is the value of marine biotechnology used during production for the genotyping of eggs associated with selective breeding practices, PCR-based screening for fish health, or vaccine development.

Biomass-related markets

Markets for biomass-derived products, many of them marine-derived, are generally well established and offer some useful data. Seaweed-derived polysaccharides (including those derived from agar, alginates and carrageenan) have mature and relatively stable markets: 86 000 tonnes and USD 1 018 billion in 2010 (Bixler and Porse, 2010). These marine-derived compounds and derivatives are used in sectors ranging from food supplements to cosmetics to health care. In 2005, it was estimated that the biopolymer “woundcare” sector in which alginates and chitin are found was worth USD 800 million a year (Anonymous, 2005).

Globally the markets for chitin and chitosan (both largely marine-derived) are worth USD 481 million and are dwarfed by the market for chitin and chitosan derivatives (e.g. glucosamine) which are forecast to reach USD 63 billion and USD 21.4 billion, respectively, by 2015.[13] However, beyond specific products, it is not easy to break down the contribution of marine biotechnology to these global markets.

The market for algal biomass (for use in biofuels) is small and immature but is expected to grow exponentially in the next 5-10 years as demand increases. The size and value of the market has yet to be determined and will clearly depend on externalities such as production costs and rates, life-cycle analysis and government policies regarding use of renewable fuels.

The market for functional foods and natural products, including dietary supplements, natural and organic foods and beverages, functional foods and beverages, and natural and organic personal care and household products, was estimated at USD 270 billion in 2008[14] and is forecast to grow at around 6% through 2015. Again, with a few notable exceptions, it is difficult to separate out the fraction derived from marine bioresources. The global market for marine and algae oil omega-3 ingredients, estimated at USD 244 million in 2009, is forecast to reach USD 476-664 million by 2015 (based on estimated annual growth rates of 10.9% to 17.3%).[15]

Economic contribution of the oceans

Marine biotechnology contributes to the bioeconomy by creating jobs throughout the value chain from academic positions to positions in industry. However, it is also expected to affect many value-added sectors: pharmaceuticals, food, industrial processing, nutraceuticals, etc. This makes its precise economic impact difficult to determine. Some useful information might be obtained by looking at the economic contribution of the oceans as a whole, but data from existing studies suggest that marine biotechnology accounts for a relatively small fraction of marine-related activities, which include oil and gas, tourism, ship building, shipping, ports, etc.

In the United Kingdom in 2005-06, direct marine-related activities accounted for 4.2% (GBP 46 billion, at base prices) of total UK gross domestic product (GDP), and marine-related jobs represented 2.9% (890 000) of total UK employment. This equates to a total direct and indirect contribution to the UK economy of between 6.0% and 6.8%.[16] Marine-related R&D accounted for less than 1% of these economic activities (Pugh, 2008).

In Canada it was estimated that in 2001 marine activities contributed 1.4% to Canadian GDP although in the maritime provinces of British Columbia and Nova Scotia the percentages were 7% and 10%, respectively (Pugh, 2008). More recently, a Canadian report on the economic impact of marine activities in large ocean management areas (Pinfold, 2009) estimated that marine activities contributed 16.1% to GDP and accounted for 127 000 jobs.

In the United States, the National Ocean Economics Program (NOEP) estimated that in 2009 the ocean economy of coastal states represented value of USD 223 billion and accounted for 2.6 million jobs. The economic value derived from "living resources" (fish hatcheries and aquaculture, fishing, seafood markets and seafood processing) in the United States was estimated for 2009 at USD 5.7 billion and 58 000 jobs.[17] However, it is difficult to separate out the contribution of marine biotechnology to these economic statistics.

Despite some very tangible market successes, and some accurate regional economic data, quantifying the contribution of marine biotechnology to the bioeconomy remains a significant challenge. However, in today's world, determining the impact of investments and maximising return on investment is more important than ever.

Measuring inputs to marine biotechnology

Some believe that the potential of marine biotechnology is equal to that of land-based biotechnology, but that the field is too young to be measured by economic output indicators and should be measured using R&D and innovation indicators.

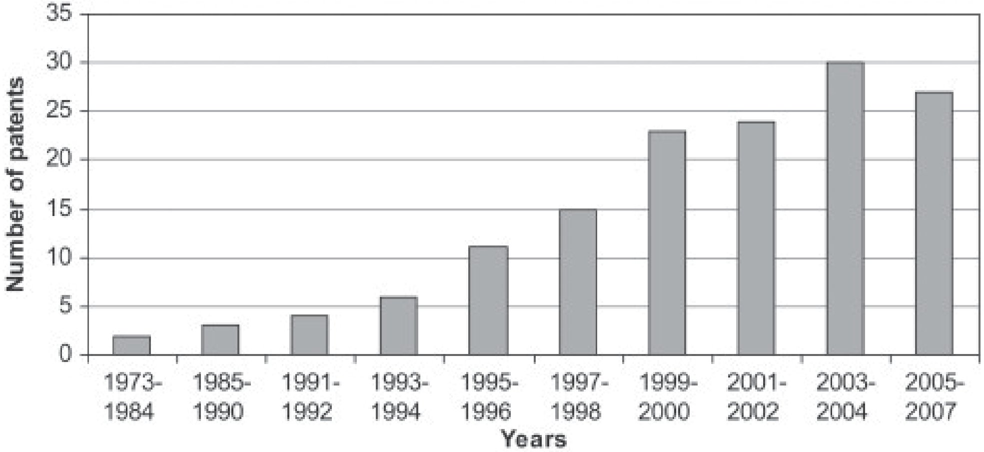
The OECD Scientific and Technological Indicators Database lists a number of input indicators related to R&D, such as gross domestic expenditure on research and experimental development (GERD) and financing patterns, to measure the output of scientific and technological activities. In particular, it contains three proxy indicators for innovation that could be useful in this regard: patents, the technology balance of payments and trade in R&D-intensive industries (OECD, 2009b). Most consideration to date has been given to patent data.

Patent data

Patents are often a significant part of the overall process of commercialising innovations. This is the case for marine–based resources and related innovations and, for this reason, patents can to some extent be considered a proxy for the commercial value of discoveries (Leary et al., 2009). Some data on marine biotechnology-related patents are available and worth examining as an indication of the growth and economic potential of the field.

In one survey, patenting was studied over a ten-year period using the database search terms: marine, sea, ocean, deep water, and sea water. This study identified a total of 2 241 patents related to marine biotechnology granted during 1996-2005 in nine different fields (Anonymous, 2010).

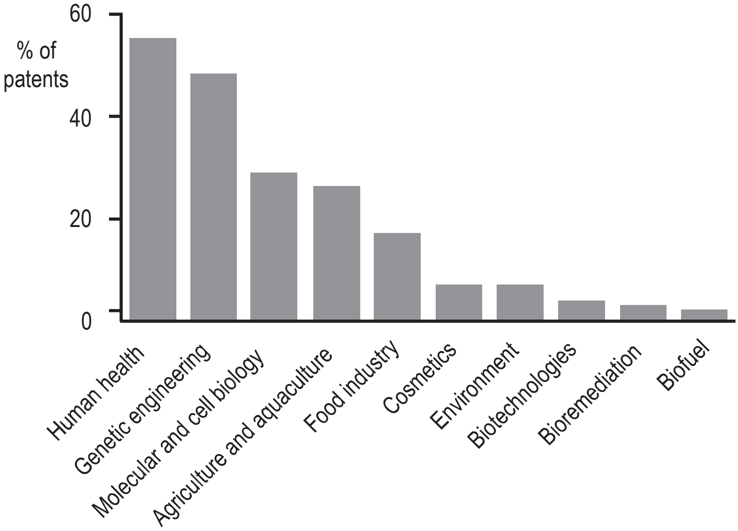
Figure 3.1. Marine genetic resource patents (patents files, n=135)



Other sources (in Hunt and Vincent, 2006): 14 000 novel chemicals; 300 patents on marine natural products.

Source: Adapted from Leary et al. (2009), "Marine genetic resources: A review of scientific and commercial interest", *Marine Policy*, 33:183-194.

Figure 3.2. Patent distribution



Source: Arrieta et al. (2010), "What lies underneath: Conserving the oceans' genetic resources", *Proceedings of the National Academy of Sciences* 107(43):18300-18305.

Leary et al. (2009) looked at patents associated with marine genetic resources (Figure 3.1) and identified 135 patents filed between 1973 and 2007. Arrieta et al. (2010) also restricted their analysis of patents to those associated with the genes of marine organisms and identified 460 claims in ten different fields of use (Figure 3.2). The available data indicate an increase in the number of marine biotechnology patents associated with marine genetic resources and demonstrate the wide variety of applications associated with patents in just one area of marine biotechnology.

However, in this field, as in many others, the use of patents as an output indicator of R&D or as a proxy for commercial success is limited. Not all inventions patented are commercialised and not all commercial successes are patented. Additionally, differences in patenting practices between publicly funded and privately funded research complicate the picture, since patenting is more prevalent and happens at a faster rate in the private sector (Leary et al., 2009).

Other indicators

The Marine Biotechnology Working Group of the Marine Board (European Science Foundation) attempted to map indicators of success and found that it was very difficult, and in some cases impossible, to obtain the necessary information. The working group was able to measure some key parameters of scientific outputs: funds and manpower devoted to marine research and technological development; scientific publications and their impact (citations); European patents by marine science and technology sectors; and information on the objectives, current status and results of various research and technological development initiatives and programmes, both at national and European level (ESF, 2002). However, information pertaining to businesses and economic outputs was hard or expensive to obtain and difficult to interpret.

The need for new measures

Measuring the commercial successes and economic impact of investment in science and technology is important (OECD, 2010). It is especially important for emerging fields such as marine biotechnology which stand to be significantly influenced by policy. There is a need to assess the impact of direct and indirect investment by governments and other stakeholders and to measure progress along the discovery and development continuum.

For marine biotechnology, some information can clearly be gained by looking at some of the indicators mentioned above. However, these are generally inadequate indicators of eventual commercial success. This raises the question of how governments and other stakeholders can monitor and assess the development of the field and its contribution to the economy. It may be that new measures and indicators are needed, or that new data need to be collected.

In some sectors indicators and measures are already in place. For example, a large body of statistics relating to R&D inputs and outputs is available for the pharmaceutical industry. Moreover, this industry is actively exploring the potential of marine-derived compounds to help strengthen a drug development pipeline that has suffered from declining productivity in recent years (Schmid and Smith, 2005; Di Masi et al., 2003; Peck, 2007).[18] In this sector, the rise in marine-related patents as a proportion of all patents related to drug development can be used as an indicator of the increasing contribution of marine biotechnology. This output, linked to marine biotechnology R&D inputs such as funding, may provide a partial picture of the economic impact of marine biotechnology. However a more complete picture will be required both for this sector and for others.

Development of appropriate measures and indicators of inputs and economic outputs will require a common definition of marine biotechnology. This would make it possible to see the types of investments being made and the types of innovations being produced. The work might also include an analysis of the business models used by certain sectors and a broad range of socioeconomic indicators in order to describe the status and evolution of marine-related activities, such as economic added value and the employment generated by various branches of marine research and technology. For reasons of manageability, the focus could initially be on a few countries and then be extended and validated by a study of additional countries.

Non-market value of the ocean

In striving to measure, and realise, the economic potential of the ocean and its bioresources, it is important to consider the non-market value of the oceans, e.g. the environmental (ecosystem services) and recreational value that can be derived from the ocean, and to recognise how these are affected, positively and negatively, by marine biotechnology applications.

In a controversial and widely cited study, Costanza et al. (1997) estimated the economic value of 17 ecosystem services for 16 biomes using a number of published studies and original calculations. They looked at the value of gas regulation, food production, waste treatment, climate regulation, etc., and estimated that the average global value of ecosystem services provided by the marine environment (open ocean, coastal regions) to be USD 20 949 x 10^9 a year.

The National Ocean Economic Program (NOEP) at the Center for the Blue Economy at the Monterey Institute of International Studies has also looked at the non-market value of oceans. Its website[19] provides links to a number of (mainly US) studies related to the non-market value of oceans used in their valuation.

Non-market values are often linked to the recreational benefits of ocean and coastal environments, or the environmental services they supply, but these values also extend beyond any direct-use benefits that the oceans and coasts provide. NOEP tries to estimate the value to society of things such as pristine beaches in California, abundant wildlife in the Florida Keys, or wetland and mangrove systems that help mitigate storm damage off the Gulf Coast (Anonymous, 2006). While the value of these “intangibles” is difficult to estimate, it is important to try to include their value when measuring the contribution of the marine environment to the economy.

Non-market values are not insignificant. In the United States alone, the NOEP analysis suggests that the total non-market value of ocean and coastal resources is, at a minimum, tens of billions of dollars a year and likely to be much more. In Florida, for example, it is estimated that the non-market value of seven activities ranged from approximately USD 16.5 billion to USD 53 billion a year (Pendleton, 2007). Excluding these non-market values would underestimate the true value of the ocean economy.

An alternative to considering the non-market value of the ocean and marine resources is to consider market values in the absence of these resources. The Stockholm Environment Institute takes this approach and looks at the lost value of the oceans under different climate change scenarios (Table 3.1). Even in a low climate impact scenario, it is estimated that over USD 1 trillion in value (0.06% of GDP) may be lost by 2050.

Any economic assessment of ocean and coastal resources should include a thorough accounting of market and non-market values to enable well-informed decisions regarding the use and development of ocean resources. Given the difficulty of valuing these less tangible or quantifiable non-market values, and the delicate balance to be achieved between ocean productivity and sustainability, a need for additional socioeconomic and environmental indicators of ocean health has been suggested (ESF, 2002).

Table 3.1. Valuation of selected climate impacts on the ocean (USD billions of 2010)

	Low climate impacts		High climate impacts		Difference	
	2050	2100	2050	2100	2050	2100
Fisheries	67.5	262.1	88.4	343.3	20.9	81.2
Sea-level rise	10.3	34.0	111.6	367.2	101.3	333.2
Storms	0.6	14.5	7.0	171.9	6.4	157.4
Tourism	27.3	301.6	58.3	639.4	31.1	337.7
Ocean carbon sink	0.0	0.0	162.8	457.8	162.8	457.8
Total	105.7	612.2	428.1	1 979.6	322.5	1 367.4
Percent of GDP	0.06%	0.11%	0.25%	0.37%	0.18%	0.25%

Source: Valuing the Ocean: Draft Executive Summary, Stockholm Environment Institute, www.sei-international.org/publications?pid=2064.

Indicators of healthy oceans

Environmental indicators could contribute to effective resource management and protection protocols. These might include biological, geological, chemical and physical indicators that characterise the health of coastal waters, the nature of pollutants and their relation to human activities and urban concentration. While some national indicators and information may exist, they are generally limited and not comparable among countries (ESF, 2002). Further work is required to:

- Define and analyse the policy value of relevant quantitative indicators.
- Identify existing primary science and technology indicators and socio-economic data on a sectoral and national basis.
- Analyse the validity and relevance of such indicators and data for policy development, such as a demonstration of sustainable development options adapted to regions.
- Synthesise existing indicators with a view to developing international indicators, including benchmarking of indicators and practice.
- Publish and disseminate regular reports on the state of the ocean and on marine activities based on these indicators.

Such data could contribute to comprehensive databases on scientific, technical and socioeconomic competencies relevant to policy making.

Conclusion

Marine biotechnology can contribute to the bioeconomy through the development of innovative products and services in sectors such as food, health and manufacturing and through job creation. To the extent that marine biotechnology can contribute to the sustainable use of ocean bioresources, it can help to preserve the non-market value of the ocean and associated socio-economic benefits (e.g. recreation, cultural traditions, tourism). The ability to measure the socioeconomic contribution of marine biotechnology is important for a number of reasons and will necessarily underpin and influence its future development.

The market value of some marine biotechnology products and services is known, yet for others the size and value of the market is difficult to estimate. Difficulties arise both for tracking the range of products and services across different sectors and for separating out the contribution of marine biotechnology from other factors. It will be necessary to reach a common understanding or definition of marine biotechnology in order to develop appropriate indicators of inputs and outputs. Given the range of applications of marine biotechnology, development of indicators and measures might usefully focus initially on a few products or outputs in a few countries before being extended to and validated for marine biotechnology outputs in other countries and sectors. The larger goal is the development of economic indicators and metrics suitable for comparative analysis across countries and over time.

Owing to the delicate balance to be struck between ocean productivity and sustainability there is a need for indicators that can provide an "economic assessment" of healthy ecosystems. These indicators might include measures of biodiversity and pollution and provide information regarding the fitness of ocean bioresources, as these are the foundation of marine biotechnology and thus of its economic potential.

Notes

1. As a relatively new concept the term “bioeconomy” is interpreted in different ways by different actors (OECD, 2009).
2. www.sitra.fi/en/natural-resources-strategy, accessed August 2012.
3. www.pmg.org.za/report/20120222-department-science-technology-grand-challenges-bioeconomy-committee-d, accessed August 2012.
4. www.whitehouse.gov/sites/default/files/microsites/ostp/national_bioeconomy_blueprint_april_2012.pdf, accessed August 2012.
5. www.prweb.com/releases/2011/1/prweb8041141.htm, accessed March 2011.
6. http://aquafind.com/articles/Marine-Biotechnology.php.
7. Mayekar et al., n.d., “Marine biotechnology: Bioactive natural products and their applications”, http://aquafind.com/articles/Marine-Biotechnology.php.
8. DNA polymerases have been isolated from hyperthermophiles for use in the process of DNA amplification known as polymerase chain reaction. These unusually thermostable polymerase enzymes, such as *Taq* DNA polymerase, must withstand the alternating cycles of heating and cooling in the PCR process if the target DNA is to replicate. See: http://nano.nstl.gov.cn/sea/MirrorResources/1895/Extremophiles.cfm.html.
9. www.highseasconservation.org/documents/juniper.pdf.
10. Salmonid aquaculture has been growing steadily since the late 1970s. It is the source of the majority of salmon available in most markets and may become an environmentally sustainable response to the depletion of wild stocks by capture fisheries.
11. www.fao.org/fishery/culturedspecies/Salmo_salar/en.
12. Molecular aquaculture involves the application of molecular techniques to rearing of fish through genetic breeding, molecular fish health diagnostics, vaccines, etc. See http://ec.europa.eu/research/bioeconomy/pdf/cwg-mb_to_kbbenet_report_final.pdf.
13. www.prweb.com/releases/chitin_chitosan/derivatives_glucosamine/prweb4603394.htm, accessed August 2012.

14. http://newhope360.com/nutrition-business-journal-reviews-270-billion-global-nutrition-industry, accessed August 2012.

15. www.frost.com/prod/servlet/press-release.pag?docid=207388177, accessed August 2012.

16. The authors write: “The scope is taken to include those activities which involve working on or in the sea. Also those activities that are involved in the production of goods or the provision of services that will themselves directly contribute to activities on or in the sea. This restricted definition is based on the understanding that the figures produced are minimum estimates of the economic importance of marine resources and activities.”

17. www.oceaneconomics.org/Market/ocean/oceanEcon.asp.

18. In addition to rising costs and traditionally long development times, new drugs represent a very small (7% in 2009) and decreasing portion of sales for the industry as a whole, with many companies including in their portfolio generic drugs and easily developed “me-too” compounds developed by other companies targeting the same disease and relying on a similar action mechanism, www.reuters.com/article/2010/06/27/us-pharmaceuticals-rd-idUSTRE65Q3IM20100627, accessed January 2012.

19. www.oceaneconomics.org/nonmarket/

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