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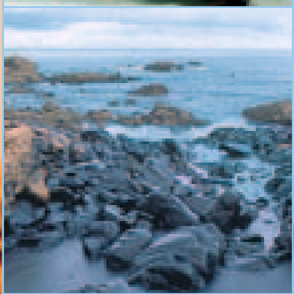
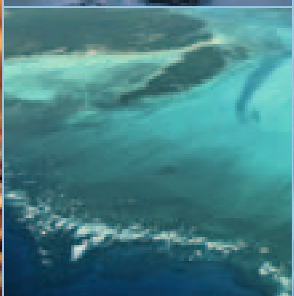
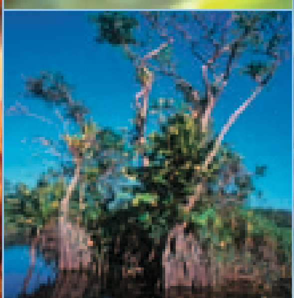
The Value of our Oceans

The Economic Benefits of Marine Biodiversity and Healthy Ecosystems







A school of sprat fish in a Red Mangrove shallow reef in Carrie Bow Cay, Belize © Michel GUNTHER / WWF-Canon

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Introduction

People love the oceans. Millions of tourists flock to the world's beaches, and whale and turtle watching, snorkelling and diving leave people in amazement of the beauties of marine life. Zoos and public aquaria, TV documentaries and even big screen cinema conveniently bring the experience of the marine world to our homes. And there, we enjoy the variety, fine taste and healthiness of seafood. The oceans give a lot – but we have not been very thankful.

The marine environment is in a dire state. Fish stocks, particularly those of greater economic value, are under heavy pressure from overfishing. Destructive fishing practices such as bottom trawling and dynamite fishing destroy the very coral reefs that are home to the fish. Coastal development claims beaches where turtles were born and to which they can no longer return to lay their eggs. Mangrove forests are cleared to make way for shrimp farms.

And climate change and ocean acidification may prove to be the hardest challenges for our oceans' species, habitats and long established food webs. And although the problems are known, solutions have been found and promoted extensively, the world is still a far cry from halting the loss of biodiversity.

With this report we want to take an economic angle in shedding light on the values we receive from the oceans and the life therein, but which we usually take for granted. The marine environment, its habitats and species have shaped and are still shaping our world, our culture and many people's daily lives. We want to show what the loss of healthy oceans will mean to our economies and individual people's incomes and livelihoods. We want to show what we loose if we don't change.

A fisherman and his son in Madasgascar *© WWF / Ralf Maro*

Some facts about healthy oceans

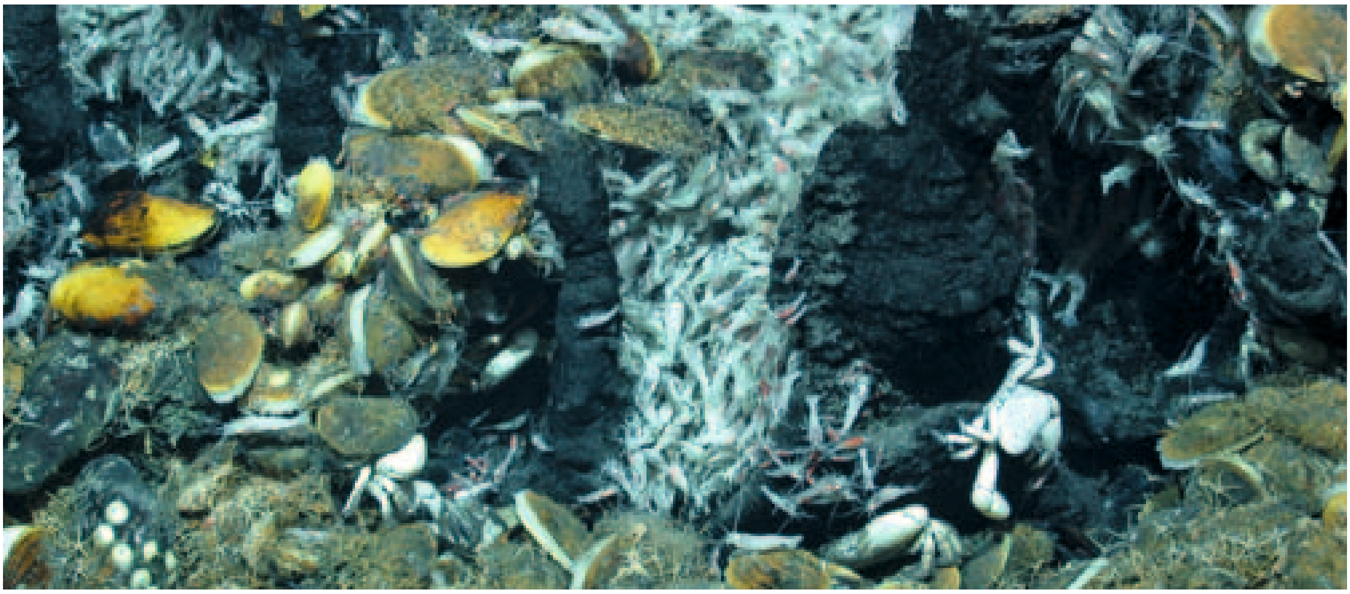
Healthy oceans provide a wide range of goods and services essential for human life. Provision of food and medicines or the detoxification of pollutants and the recycling of nutrients are functions of the ocean which create value for human users. Such essentials are called 'ecosystem goods and services'. These goods and services are 'for free' but require intact marine ecosystems: Coral reefs, kelp forests, mangroves, salt marshes, mud flats, estuaries, rocky shores, sandy beaches, seamounts, abyssal plains and open oceans – each of these habitats contributes to the oceans' ability to serve essential goods and services.[1]

The sea accommodates 32 of the 33 animal phyla known in biological taxonomy; 15 phyla thereof can be found exclusively in marine habitats. Today's biodiversity – the diversity of habitats, species, genes and structural design - is the result of 3,500 million years of ongoing evolution and still largely unknown to us. Currently, over 200,000 marine animal species alone have been described and reside in collections. To improve scientific knowledge, the 'Census of Marine Life' started in 2000. A global network of researchers in more than 80 nations is engaged in a 10-year scientific initiative to assess and explain the diversity, distribution and abundance of life in the oceans. Since the project started more than 1,000 new species have been found already, including over 100 new fish species, and the scientists involved aim to add many thousands more by 2010. The overall number of marine species – if ever fully explored – may be in the range of 10 million – compared to 1.5 million described terrestrial plants and animals.[6]

„About the ocean we know less than about the moon" is a frequently quoted slogan when oceanographers talk about animals and plants in the oceans. Only the coastal zone and the upper light-flooded layers of the ocean are somewhat investigated, but 80 percent of the ocean, which means 62 percent of the entire earth's surface, are deeper than 1,000 meters. Here it is difficult to observe the life directly and scientists depend on tools like nets, weirs and grabbers or remotely operated vehicles. As a result species are caught selectively depending on the sampling method used – but never the whole spectrum of species at a place. Furthermore, marine fisheries research is largely concentrating on economically important species.[4] The major diversity anyway resides in the microbial life that can be found in marine waters, on the surfaces of plants and animals, and in the deep-sea sediments.[5]

In spite of the ocean's vastness it is not one big habitat. Micro-endemic life-forms can be restricted to small geographical features like isolated island platforms or coastal lagoons or the cadaver of a whale in the deep sea (which is also a unique habitat called 'whale trap'). A study of the Food and Agriculture Organization of the United Nations (FAO) on marine resources in the Western Central Atlantic lists 23 percent of the 987 fish species treated in detail as rare or endemic to the study area. The study summarizes: "Such a high level of endemism stands in contrast to the widespread view that marine species characteristically have large geographic ranges and that they might therefore be buffered against extinction."[2]

Crustaceans and mussels on a 'black smoker', a hydrothermal vent in the deep sea. Scientists reckon that life on earth may have originated in this habitat *© Marum Bremen*

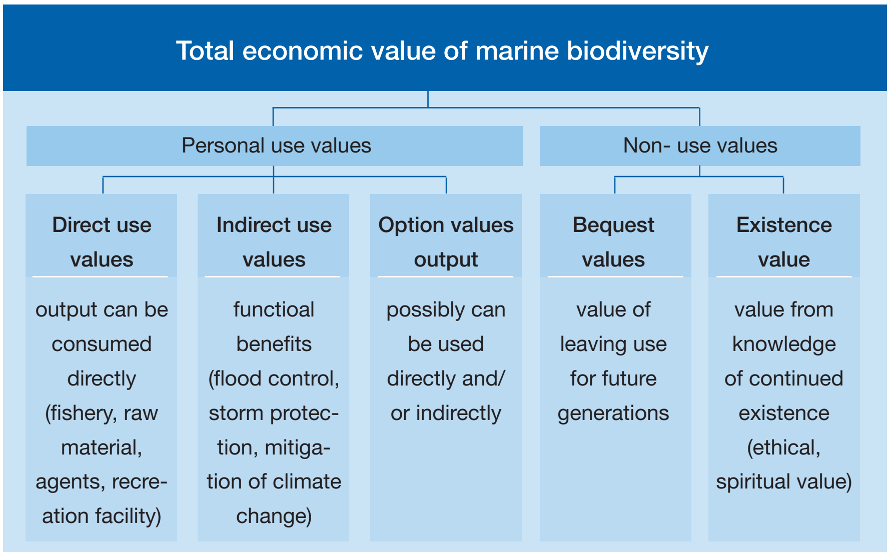


Valuating marine biodiversity

Our study attempts to estimate the economic value of marine biodiversity, well knowing that an economic valuation cannot show the overall value of biodiversity. Unfortunately ecosystems are poorly understood, scarcely monitored, and (in many cases) undergoing rapid degradation and depletion. Often the importance of ecosystem services is widely appreciated only upon their loss[8] and only in some cases – like bioprospecting access agreements or direct payments for habitat conservation – capture demand for biodiversity directly.

The overall value of marine biodiversity can be outlined as below:[9]

Figure: Categories of economic values



Partly the ecosystem goods and services of marine biodiversity are traded in the market and market prices can be used as indicators for economic values. But a broad range of goods and services have no market price and shadow pricing techniques are necessary to determine their economic values, for example: [8, 10]

- The Contingent Valuation Method asks people directly what they are willing to pay (or to accept) if a specific change in the environmental quality can be reached.
- The Travel Cost Method estimates the value of a special location by valuing time and travel cost expenses that people incur to visit a particular site.
- The Production Function Approach estimates how the ecological input into economic production will change if the environment changes.
- The Net Factor Income Approach goes the other way round and states the economic surplus of ecosystem goods and services as the remaining value when other inputs in production has been subtracted from the total revenue.
- The Total Revenue Approach estimates the value given by the direct sale of ecosystem goods and services.

About ten years ago a scientific study caused quite some commotion, when a team of researchers led by Robert Costanza attempted to calculate the value of nature. Valuating a variety of ecosystem services they arrived at the following conclusion: “For the entire biosphere, the value (most of which is outside the market) is estimated to be in the range of US$ 16-54 trillion per year, with an average of US$ 33 trillion per year (or US$ 33, 000, 000,000, 000 per year). Because of the nature of the uncertainties, this must be considered a minimum estimate. Global gross national product total is around US$ 18 trillion per year.” The study also shows that 63 percent of the estimated value of the entire biosphere is contributed by marine systems (US$ 20.9 trillion per year), most of this originating from coastal systems (US$ 10.6 trillion per year). And these “are all only static snapshots of a biosphere that is a complex, dynamic system.”[11] Despite profound methodological critique for the simplified calculation the scientific community certified the authors a most valuable thought-provoking momentum initiating a huge amount of follow-up research and public discussion.[12]

Many studies have looked at the valuation of biodiversity, mainly with a limited scope, focusing on single habitats or aspects or taking a specific nation’s or regions point of view. Defra, the UK’s Department for Environment, Food and Rural affairs has, however, in 2006 commissioned an estimation of monetary values of marine ecosystem services of Great Britain’s waters. [13, 14] Eight of thirteen goods and services could be valued in monetary terms, with varying degrees of confidence, from food provision over nutrient cycling to cognitive and bequest & existence values.

In the following sections of this study we will shed some more light on the economic valuation of marine biodiversity and healthy marine ecosystems by highlighting some figures, examples and also people who benefit from the sea’s riches.

Tourism, recreation and leisure

The value of marine biodiversity for recreation and leisure purposes is an economically important factor with 898 million arrivals in 2007 and an annual growth of about 5 percent worldwide.[1]

In some cases the relation between tourism activities and marine biodiversity is obvious: coral reefs account for about 40 percent of the world's known marine fishes[2] and are therefore a paradise for diving and snorkelling. As Bishop and colleagues stated: "The business case for biodiversity conservation is most easily made when the business in question depends directly on biodiversity to operate and survive. Conservation based tourism is a good example where the income stream to private enterprise depends directly on the health of the surrounding ecosystem."[3] In this way tourism is one of the few economic activities which captures demand for biodiversity directly.

Saba Marine Park (Netherlands Antilles) shows how a protected area can be completely financed by tourist revenues. The park was established in 1987 with grants totalling US$ 270,000 from the island government, the Dutch Development Corporation and private foundations. The management of the park has been delegated to an NGO, the Saba Conservation Foundation. The Foundation has a threefold strategy to generate revenues:[4]

- User fees for divers and snorkellers collected by commercial operators, and yacht mooring/anchorage fees brought in 70 percent of the park's revenue in 2003.
- Saba Marine Park runs a successful 'Friends of Saba Conservation Foundation'. Promotion activities encourage park visitors to register, give donations, and receive information via a newsletter. Subscriptions start at US$ 25 per year (Friend), rising up to 5,000 per year (Patron).
- The park sells a variety of souvenirs and allocates the park logo for sponsoring activities, thus covering around 18 percent of its budget.[4]

How tourists can add value to their destination:

The study 'Tourism for Protected Area Financing: Understanding tourism revenues for effective management plans' presents a number of examples on how an MPA's income can be generated:[4]

- Entrance fees to be paid for visiting a protected area.
- Fees for using park facilities and tourist infrastructure.
- Concessions like anchoring points for commercial boat owners.
- Taxes for all travellers entering or leaving certain regions.
- Voluntary donation schemes to support protected areas and the work of local NGOs.
- Direct operation of commercial activities like souvenirs, brochures, local products, sets for filming etc.

Diving is the activity which has the highest value among all recreational activities. A meta-analysis of 52 coral reef valuation studies showed an average value of US$ 184 per visit with considerable differences between locations, depending on image, tourist infrastructure, and recreational activity.[5] In 2000, net annual benefits from dive tourism in the Caribbean totalled just over US$ 2 billion with US$ 625 million spent directly on diving on reefs.[6] The 2001 Travel and Tourism Satellite Accounts (TSA) developed by the World Travel and Tourism Council estimated that by 2001 the economic impact of tourism in the Caribbean was greater than in any other region in the world. Tourism accounted for roughly 17 per cent of total Caribbean GDP and was estimated to generate 2.5 million jobs in the region.[7]

Other recreational activities can also create valuable economic benefits. In California whale watching and other types of marine wildlife viewing are estimated to generate over US$ 25 million per year in gross revenues. Annual expenditures associated with recreational fishing in California reached the enormous amount of US$ 545 million in the year 2000.[8]

The example of Sea Turtle Tourism

A study undertaken by WWF International reached the conclusion that people working with wild sea turtles can earn three times as much in tourism activities as they can through the taking of the tortoiseshell, meat and eggs for trade.[9]

The study analysed nine case studies of consumptive use, which include examples of use for meat, shell, eggs, bone and leather in countries bordering the Atlantic, Indian and Pacific Oceans. Gross average revenue from these sites was US$ 581,815 per year, and the highest revenue was US$ 1,701,328.

Against these findings another nine case study sites of non-consumptive marine turtle use have been analysed. The revenue from these sites, where turtles are a major tourist attraction, included all expenditure (food, accommodation, souvenirs, transport and other costs) incurred by tourists during their time at the turtle watching location. While the lowest annual revenue was US$ 41,000 and the highest US$ 6.7 mil-

Turtle watching provides three times more income than a consumptive use *© Michel GUNTHER / WWF-Canon*

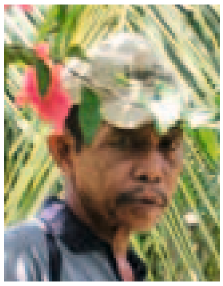
lion, the median was US$ 975,044, over three times higher than in the consumptive-use sites.

In the most established site in Tortuguero National Park in Costa Rica the average annual revenue was US$ 1.6 million[9]. At the same time, relatively simple conservation strategies can have a profound effect on the recovery of once seriously depleted turtle stocks.[10]

The Bunaken National Marine Park

The Bunaken National Marine Park in Indonesia presents a striking example of the economic influence of nature-oriented tourism activities. Located near the centre of Indonesia, it was established in 1991. Approximately 30,000 people live in the 22 villages inside the national park. Fishing and farming are the traditional livelihoods in the area, but tourism has recently become a driving force in the local economy.[11] In the Bunaken MPA, the tourist industry provided new occupations to local villagers, and those who switched to a new occupation earned more than twice as much as fishermen (US$ 114 versus US$ 44 a month).

We asked three of them to share their experiences with us:



Yunus describes benefits from entrance fees:

“My name is Yunus, but I also used to be called Pak Unu. A few years ago, I used to work as a farmer and fisherman, but now I work as the Visitor Centre’s Manager, located at Liang Beach.

The tourism activity brings relief for the locals. The opening of the national marine park caused investors to come and it means a new working field opened for locals. 20 years ago, this Alung Banua village was quite old fashioned, and people were a bit left over. In the old days, people had to work on the mainland, or up in the mountains as coconut climbers. Now, they can work here in tourism, and it means

Tourism can provide a wide range of job opportunities to the local community
© Birgit Weerts / WWF

no more unemployment. They now also work as patrol officers. That's all because of the benefits from Bunaken National Marine Park.

The inhabitants used to complain about the park's entrance fee. They felt the national park was belonging to them, and why should tourists visiting have to pay? But through a long process of socialization, people became aware that by the entrance fee the national park area could be protected. And that if it was not protected there would be damage, and guests would no longer visit this place.

There are many benefits from the entrance fee; roads and infrastructure are developed and there is also school education in the village paid from the entrance fee."

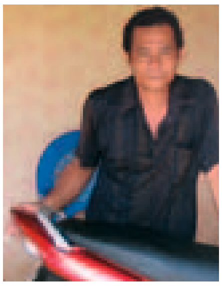
Desmond Julian works as patrol officer:

"My name is Desmond Julian. I was a farmer and fisherman. Since four years, I work as patrol officer for the national park.

Well, at first, people didn't understand the patrol's duty, but we explained that we are here together with the society to protect the National Park. It does not belong to the patrol but to the society. Now we have the support of almost all people, and violations have significantly decreased after the established of the patrol.

Years ago, people were free to take the fishes from any area. Now we have different zones to regulate our fishing and so, and by the preservation we've done, such as corals planting, fishes grow significantly more. That is because now people here are aware of the MPA.

Alung Banua villagers in the old days couldn't sell the fish at a good price, but now whenever fisherman catch fishes, they can sell it on the tourist cottages at a good price."



Kores Ojuriaw owns a new motorbike:

"My name is Kores Ojuriaw. I used to work as fisherman, and now I work as patrol officer.

It is different between now and the old days. In the old days, there were so few jobs here, but now, with the MPA established and the tourism, 90 percent of the people can now work in the island. What happens here in Bunaken can be a model for other regions.

I now have more money, we have a better life. I have built our own freshwater reservoir for my family which is good for our health. We have a fridge and I am happy about my new motorbike which increases my mobility on the island."

From 2001 to 2004, the number of visitors in Bunaken increased by 152 percent. Diving tourism also created more high-income job opportunities for women, enabling them to improve their livelihoods by producing and selling goods and through new jobs as grounds keepers, waitresses, etc.[11,12] Overall, 1,063 jobs have been created in Bunaken's tourism sector since 1998, a substantial part of the regional labour market which has a work force of about 15,000; so the whole tourism sector now employed more than 30 percent of the villagers on Bunaken Island in 2005.[11]

The multi-stakeholder Bunaken Management Advisory Board introduced a system of entrance fees simple enough not to inconvenience visitors, which does not force daily queuing at a single entrance gate. Tourists have the possibility to pay at three different windows within the park, and local tour operators can also sell tickets. A robust control system via a boat and land based patrol system with spot checks by park rangers ensures that all visitors are charged and opportunities for corruption are minimised. The tickets to use the park's facilities are US$ 6 per day or US$ 17 for one year for foreign visitors. Local people pay less than 10 percent of the fees for foreigners. 80 percent of the funds collected from the entrance fee system are used specifically for conservation programs in the park.

Diving and snorkelling are directly dependent on the health of the marine envrironment © Birgit Weerts / WWF

The entrance fees to the Bunaken National Marine Park are also used for infrastructure improvement and education *© Birgit Weerts / WWF*

During 2001-2003 over US$ 250,000 were raised for conservation programs including enforcement, conservation education, trash management and environmentally-friendly village development. The remaining 20 percent is split between local, provincial, and national governments and provides an incentive for governments to continue to support the scheme. In 2003 Bunaken won the British Airways Tourism for Tomorrow award.[13]

The Wadden Sea National Park

Closer to home we can take the Wadden Sea National Park as an example of a tourist-based economy. The National Park located on the Dutch, German and Danish North Sea coast is one of the world's largest and most important intertidal wetland ecosystems and is visited by over 10 million tourists per year. The economic value of the protection and use only of the German part of the Wadden Sea National Park area has been assessed as US$ 31.2 million.[14] This assessment includes expenses incurred by people to arrive at and enter the Park, donations to NGOs and the National Park administration, tourism activities within the National Park area, the maintenance of the salt marshes by pasturing sheep, and the National Park fishery. As the economic value generated within the National Park must be offset with the US$ 18.8 million actual costs to maintain and manage it, the resulting annual benefit of the Wadden Sea National Park is US$ 12.4 million.

Not only entrance fees create value from tourism: added value is also created through the expenditures tourists incur for all kind of goods and services they demand during their holidays or day trips. If tourists visit a special place because of its natural quality and biodiversity, their entire expenditures must be seen as an ecologically motivated surplus for the region. In this way tourism produces most of the added value in the Wadden Sea National Park and more than half of the added value of the whole region. Tourists visiting the site because of the National Park generate a regional added value of about US$ 5,050,000, corresponding to 280 full time jobs. The much bigger group of tourists for which the national park plays an important role in their choice of destination, generated an added value of US$ 131,000,000 or about 5.900 full time jobs.[15]

The natural biodiversity within the National Park is a famous tourist attraction. In 2006 official guides offered 4,600 walking-tours over the tidelands and showed more than 100,000 guests the wealth of the marine nature. The visitors' centres within the National Park are also en vogue: the most important magnets in 2006 were the newly built Multimar Wattforum (169,000 visitors), the Seal Center (143,000 visitors) and the interactive museum on the elements (172,000 visitors).[16]

Constanze Höfinghoff markets the North Sea Coast for tourist use:

“My name is Constanze Höfinghoff and I’m the CEO of the North Sea Tourism Service GmbH. Our aim is to improve and develop tourism on the Western coast of Schleswig Holstein which includes parts of the Wadden Sea National Park. Our aim is to win new customers and – generally speaking – to strengthen the image and ‘brand’ of North Sea tourism.

Tourism is one of the most important economic factors along the shore. If we have a market collapse in this sector because we don’t care for our natural resources and cannot serve further our customers’ motivations – this would strike a heavy blow to our whole economy. We know our most important commodity and why people want to visit us.

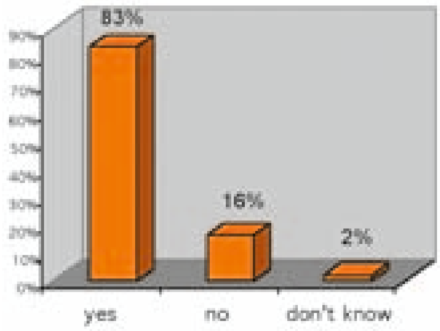
We cooperate a lot with market research institutions and in looking at current analyses we see nature and environment are important for over 80 percent of all tourists. And the share of nature holidays among all types of holidays grew up to 25 percent in 2007 with an unbroken upward trend.[17]

Coastal nature really is an event. Walking with a guide through the tidelands and learning about the enormous performance of such a small rock worm cleaning all the beaches is a really interesting thing for young and old. And this creates the win – win situation we need. Tourism brings up to 2 million guests and 14 million excursionists a year who will be informed and sensitised for nature’s concerns. And in return nature gives us unique experiences which attract the tourists.

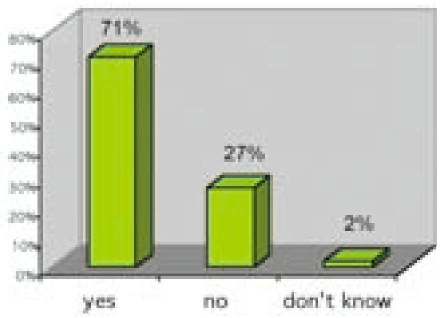
Beyond this professional viewpoint I personally enjoy the high quality of life at the coast and would never want to live anywhere else than in the ‘Land between the Seas’.”

In many case studies we find astonishing figures of added value from recreational and leisure activities, but it is difficult to determine to which degree marine biodiversity contributes to people’s decision to prefer a specific place and manner of taking holidays or short trips. The figures on ecologically motivated tourism refered to by Constance Höfinghof are, however, validated by an actual study of the NGO Europarc, which questioned more than 1,000 German tourists about tourist use and financing of natural protected areas. They obtained the following results:[18]

“Would it meet your approval if visitors of national parks contribute to the financing of such areas, for instance by visitor’s tax or entrance fees?”



“Would you prefer to make holidays in a site where it is decided to protect nature by establishing a national park?”



Guided tours are a major tourist attraction in the unique Wadden Sea
© Hans-Ulrich Rösner/ WWF

Hans Janssen, the responsible mayor of the island Langeoog:

"My name is Hans Janssen and I'm the mayor of the island Langeoog which is located at the border of the Wadden Sea to the North Sea. For us islanders life on the island would be unimaginable without the sea.

Langeoog lives nearly completely on tourism. For this we need a sound environment and rich biodiversity. The worst case would be an oil spill polluting our beaches. The guests would just stay away. In this case not only our lovely surrounding would be destroyed but also the entire economic basis of the island.

But as I said – this would be the worst case. Actually we can be proud of our sound marine environment and the wealth of plants and animals. I myself like these beach promenades when the kids can play hide-and-seek or examine stranded goods. And of course the clean air - when I go upcountry and leave the train I instantly feel the difference.

My message is that we only borrowed this island and the whole world from our children and grandchildren and therefore we have to take care of it. When I throw away a slice of bread or waste or when I needlessly drive my car– I only have to look at my kids and I know what I have to do. And also as a mayor I have to ask myself: "is it only for my self-adulation or is there long-term sense in what I do?"

Economic valuation refers not only to the positive impacts of marine biodiversity on tourism but can also be seen from the reverse perspective: deterioration of marine nature, i.e. a decrease in natural capital, results in a decrease in the economic benefit from recreation and leisure activities:

An oil spill would leave the beaches in the North Sea empty *© Hans-Ulrich Rösner/ WWF*

- Harmful algal blooms (HABs) occur when large quantities of algae produce toxic or harmful effects on people, fish, shellfish, marine mammals and birds. HABs have been reported in coastal states around the world, and their occurrence may be on the rise. HABs can adversely affect not only the health of people and marine organisms, but also the „health" of local and regional economies. Estimates of the economic impacts of HABs on recreation and tourism in the United States from 1987-92 range up to US$ 29 million with an annual average of about US$ 7 million.[32] An unusually large and persistent bloom in 2005 of the Florida HAB 'red tide' resulted in massive fish kills, unusual mortalities of protected species and reports of human respiratory irritation in residents and beach-goers. The entire range of impacts has not yet been documented but based on theorized tourism losses, the Convention and Visitors Bureau has cited potential losses of up to US$ 240 million in the Tampa Bay area alone.[19]
- In November 2002 the oil tanker 'Prestige' sank off the Northwest coast of Spain and caused one of the biggest ecological disasters in Europeans' seafaring. Tourism flows in Galicia after the 'Prestige' oil spill experienced a decrease of 4.89 million overnight stayings in 2003 and a considerable decrease in domestic excursions. Overall the oil spill caused an economic loss of US$ 86.4 million for the Galician tourism industry.[21]

Recreational opportunities are one of the most valuable ecosystem goods and services in terms of economic valuation. They are especially important for poorer and more peripheral regions which cannot participate in the booming economies of the economic centres. "The marine protected area is like a bank to the people," noted a Fijian community leader.[22]

Living oceans feed the world

The marine resource which most readily comes to mind is fish. Here an economic valuation is more straightforward than for other marine goods and services. In 2005 a total of 93.3 million tons of fish, mollusks and crustaceans were caught, 90 percent from marine capture fisheries.[1] Unknown amounts from small scale professional and subsistence fisheries must be added. Further, in addition to this catch, many million tons of fish are discarded globally, i.e. are caught and thrown away or dumped at sea. Moreover, aquaculture yielded 47.8 million tons, 18.9 million tons (39.5 percent) of which came from marine systems.

Alerting state of stocks

Global capture fisheries production peaked at 95 million tons in 2004, with an estimated first-sale value of US$ 84.9 billion .[3] China is the top producing country. World capture fisheries production has grown five-fold since 1949[4] and has been relatively stable in the past decade.[3] Due to growing food demands rising prices will continue to increase fisheries gains even with stagnant catches.

To counter stagnant or declining catches in times of growing fish demand, aquaculture has grown more rapidly than all other animal food-producing sectors, with an average annual growth rate for the world of 8.8 percent since 1970, compared with only 1.2 percent for capture fisheries and 2.8 percent for terrestrial farmed meat production systems.[3] Aquaculture production in 2004 was reported to be 45.5 million tons with a value of US$ 63.3 billion or, if aquatic plants are included, 59.4 million tons with a value of US$ 70.3 billion. Aquaculture is, however, carried out predominantly in freshwater, and marine fish account for only 2 percent of the total yield in terms of weight and 7 percent in terms of value.[3]

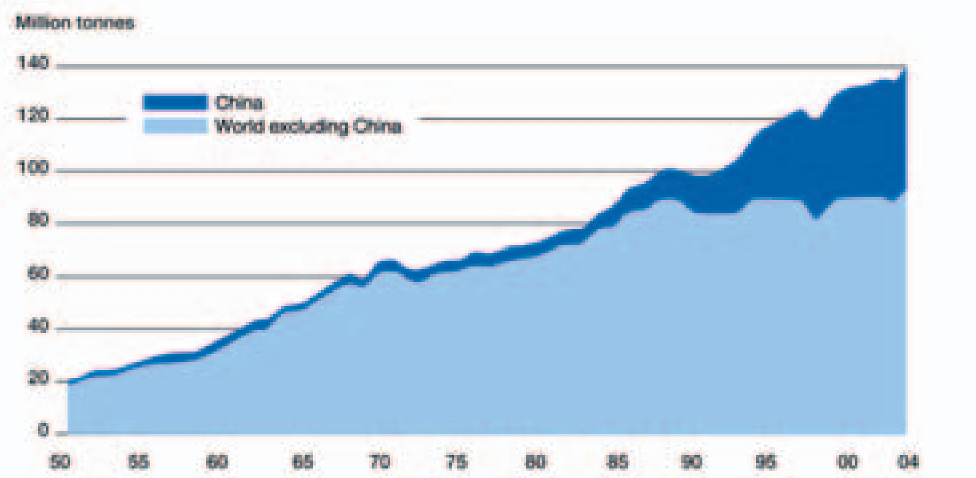
Overexploiting a resource

"Overall, more than 75 percent of world fish stocks for which assessment information is available are fully exploited or overexploited (or depleted and recovering from depletion), reinforcing earlier observations that the maximum wild capture fisheries potential from the world's oceans has probably been reached", summarizes a recent FAO report.[3] The number of the most commercially important stocks that are overfished or fished to the limit has been growing steadily for open ocean and coastal fish, and most recently even for deep water species.[4] The process of overfishing has long been masked by systematical over-reporting of some countries and the targeting of deep water stocks.[5]

Pauly and colleagues observed additional indicators of general overexploitation: The mean trophic level of the species groups reported by the FAO declined during 1950 to 1994. Fishing down food webs (i.e. towards lower trophic levels such as invertebrates and planktivorous pelagic fish) leads in the short term to increasing catches but eventually to stagnating or declining catches. The results indicate that present exploitation patterns are unsustainable.[7]

Overfishing is an important economic problem. Cod fishing in the Baltic, for example, lost US$ 128,600,000 in 2002 when compared with the amount of fish that could have been harvested if previous management had lead to sustainability. Similarly, the North Sea cod fishery lost US$ 195,300,000.[6] Overfishing is also the activity most economically detrimental to reefs in Indonesia and the Philippines. In Indonesia more than 32,000 km^2 of reefs are overfished, resulting in massive societal losses estimated at US$ 1.9 billion over twenty years. In the Philippines financial damage from overfishing of more than 21,000 km^2 of reefs is estimated at US$ 1.2 billion.[17]

World capture and aquaculture production[1]



Subsistence fisheries like here in Cayar, Senegal, can be crucial for food security *© WWF-Canon / Olivier VAN BOGAERT*

Fishing from a different angle

Millions of people around the world depend on fisheries and aquaculture, directly or indirectly, for their livelihoods. Over the past three decades, the increase in the number of fishers and aquaculturists was faster than the rate of the world's population growth.

Human fish consumption is distributed unevenly around the globe, with marked continental, regional and national differences as well as income related variations. Fish consumption can vary from less than 1 kg per capita annually to more than 100 kg. Global per capita fish consumption has increased over the past four decades, rising from 9.0 kg annually in 1961 to an estimated 16.5 kg in 2003.

In many countries, especially developing countries, average per capita fish consumption may be low, but even in small quantities, fish can have a significant positive impact on a healthy diet. Fish contributes to, or exceeds, 50 percent of total animal protein intake in some small island developing states, as well as in Bangladesh, Equatorial Guinea, the Gambia, Guinea, Indonesia, Myanmar, Senegal, Sierra Leone and Sri Lanka. Globally, fish provides more than 2.8 billion people with almost 20 percent of their average per capita intake of animal protein. The contribution of fish proteins to total world animal protein supplies was 15.5 percent in 2003.[3]
For some countries in the Pacific Islands region (e.g. Tuvalu, Kiribati, Tokelau) dependence on fish from the coastal zone as a food source is among the highest in the world. In some outer island areas, per capita fish consumption is estimated to be more than 200 kg per year. According to FAO data, fish (of which the vast majority is from coastal areas) represents 38.7 percent of the total animal protein intake in the Pacific Islands region.[3]

Generally, fisheries can be divided into three types:

- Industrial fisheries, which are conducted by few people on large boats with onboard processing facilities. The ships often belong to developed countries and exploit coastal, open ocean and deep sea stocks.
- Small scale commercial fisheries, which can be broadly subdivided into those producing export commodities, and those supplying domestic markets; and
- Subsistence fisheries, predominantly found in developing countries where they support rural economies and are extremely important to the region's nutrition and food security. They concentrate on coastal catches.

Fishing for livelihood

In 2004, an estimated 41 million people worked (part time or full time) as fishers and fish farmers, the great majority in developing countries, mainly in Asia where four fifths of world fishers and fish farmers dwell. Significant increases over recent decades, in particular in Asia, reflect the strong expansion of aquaculture activities. In 2004, the number of fish farmers accounted for one quarter of the total number of fish workers.[3]

The fisheries sector, including aquaculture, is an important source of employment and income. Employment in fishing and fish farming cannot, however, be taken as the sole indication of the importance of fisheries to a national economy. The fishing industry also generates considerable employment in shipbuilding and shipyard operations, in the fishing gear industry, in the production of technological equipment, in aquaculture feed production and in processing, packaging and transport. Statistics are not available for the total number of individuals providing inputs to fisheries and aquaculture through these activities.

In temperate regions the fishing industry is also an important business. In the EU 25 about 230,000 employees are employed directly in the fishery sector. The value of fishery products produced by the processing industry was about US$ 14,327,430 in 2003 accounting for an additional 132,000 jobs.[9]

In the UK in 2004, 654,000 tons of sea fish were landed, with a total value of US$ 1,027 million at first point of sale. Seventy percent of all landings by the UK fleet were caught in three areas: the West coast of Scotland, the northern North Sea, and the central North Sea. The UK fleet was composed of 11,559 fishermen, with 84 percent of these being full time fisherman.[10,11] The most valuable species was nephrops at US$ 123.2 million, followed by mackerel (US$ 76.4 million) and cod and haddock (US$ 62.65 million each).[12]

Further revenue and employment were created through the fish processing industry, retail sales, and exports. The 2002 UK fish processing industry was assessed as having around 530 businesses which employ some 22,500 people. At the retail level there were approximately 1,400 fishmongers.[12] The value of fisheries products produced by the processing industry was estimated at US$ 2,176,754 in 2003.[9]
In Germany 4,500 jobs depends directly on the fishery in the North Sea and Baltic Sea and further 45,000 are connected with industrial processing of fish, trade and gastronomy.[13]

With dwindling near-shore fish stock, industrial trawlers now target vulnerable deep-water fish such as Orange Roughy *© Australian Fisheries Management Authority*

Norbert Krümpelmann cultivates his resource base:

"My name is Norbert Krümpelmann. I'm the managing director of the Gottfried Friedrichs KG.

Our company processes fish – especially wild salmon – into premium products. We see our company as part of a chain of economic added value, which means that we also feel responsible for the quality and environmental care of our suppliers and therefore we offer more and more products labelled by the Marine Stewardship Council (MSC). This way of management matches our belief.

A sound marine ecosystem is the foundation of our business, and it is where we experience important changes. One example is a project in Kamchatka we are undertaking with the WWF. The project deals with wild salmon that spend their growth phase in the Bering Sea and then migrate to their spawning grounds. Part of the stock is now, however, migrating towards Japan, as they are irritated by the increased water temperatures of their normal migration route. This example shows how marine ecosystems change latterly and have a direct economic impact on our business.

Bill from Seattle told me another example. Friedrichs buys Salmon from Alaska since 1908 and our purchase director Eckard Kämmler built up the contact with this expert in Salmon fishing in 1981 during his regular visits of the fisheries in Alaska. Bill is one of our most important suppliers with Alaskan Salmon. Each year he makes one or two trips to Germany to maintain the personal contact. For two years he has been regularly reporting how the ice is melting and the icebergs are decreasing dramatically. In Germany we hardly perceive climate change in this way. But when such a person narrates his experiences it really hurts and makes me think. And of course it also has economic impacts for us because of the lower catches and smaller fish.

We have to prepare for such developments and to intervene correctively. This needs a kind of governance where we have to get all actors on board. And we must communicate to consumers that they increasingly will be able to choose seafood products that are from sustainable and well-managed fisheries. For this, the MSC label is helpful because it provides us with criteria and at the same time allows this kind of communication."

Coral reefs and mangroves are valuable fish habitats

Coral reefs account for almost 100,000 marine species, despite their combined area being just 0.2 percent of the ocean surface. There are between four and five thousand species of fish on coral reefs, about 40 percent of the world's known marine fishes.[14] Of the estimated 30 million small scale fishers in the developing world, most are somehow dependent on coral reefs. 25 percent of the total fishery in developing countries relies on coral reefs. Fifteen tons of fish and aquatic animals can be yielded annually per km^2 of coral reef.[15]
Some figures may clarify the value:

- In Indonesia, sustainable reef use enables a net gain of US$ 70,400 per km^2 and year over a 25 year time horizon, and employs 10,000 fishermen.[16]
- In the Philippines more than one million small scale fishers depend directly on coral reefs for their livelihoods.[17]
- In the Caribbean, reef fisheries generate about US$ 310 million a year and in Southeast Asia almost US$ 2.5 billion annually[18,19]

A report of the UNEP World Conservation Monitoring Centre estimates that reef fisheries are worth between US$ 15,000 and US$ 150,000 per km^2 per year. This is often in areas of the world where many people live on less than one to two dollars a day. Overall, reef fish may account for a quarter of the global fish catch, providing food for one billion people.[18,19]
The links between poverty and reefs have been explored in a major study by the UK Department for International Development: the self-reliance and economic basis as well as the nutrition of 300,000 coastal inhabitants in East Africa and 20 million coastal inhabitants in South Asia depends on healthy reefs.[20]

Mangroves are also important for fisheries. The global mangrove area currently equals about 15.2 million hectares, with the largest areas found in Asia and Africa, followed by North and Central America.[21]

Mangrove forstes are of particular importance as nursery grounds for fish and crustaceans *© Anthony B. RATH / WWF-Canon*

In Queensland, Australia, an estimated 75 percent of commercially caught prawns depend on mangroves. In Malaysia the UNEP states that a 400 km^2 managed mangrove forest in Matang supports a fishery worth US$ 100 million a year.[20] Other estimations of the economic value of the fisheries function of mangrove vary greatly: annual market value of capture fisheries supported by mangroves ranged from US$ 66 to almost US$ 16,750 per ha.[22,23]

The FAO has issued a considerable warning: "An alarming 20 percent, or 3.6 million hectares of mangroves have been lost since 1980. More recently, the rate of net loss appears to have slowed down, although it is still disturbingly high. About 185,000 ha were lost every year in the 1980s; this figure dropped to some 118,500 ha per year in the 1990s and to 102,000 ha per year (minus 66 percent) during 2000–2005, reflecting an increased awareness of the value of mangrove ecosystems."[21]

A developing and very profitable trade is in aquarium fish. Most aquarium species are relatively small, have bright coloration, and good survival in captivity. Collection operations have been established in most Pacific Island countries over the past 20 years. These fish are rarely taken for food in the Pacific Islands and therefore this fishery does not interfere with subsistence activities. The nominal reported export value of aquarium fish from selected countries in 1999 is: Fiji US$ 178,000, Marshall Islands US$ 473,000, Vanuatu US$ 16,500, Cook Islands US$ 73,500, and Kiribati US$ 1,160,000. The relatively recently-established aquarium fish businesses in the Kiribati and the Marshall Islands now account for 78 percent and 95 percent of all fishery exports from those countries respectively.[4]

Biodiversity and destructive fishery practices

Fish stocks are strongly influenced by the entire food web and vice versa. Fisheries in many areas harvest a considerable amount of the biomass of higher trophic levels of the food web, influencing the whole ecosystem. Ecosystem modelling for the Adriatic Sea, for example, identified various key factors for the stability of the food web. Among them the researchers identified simplification of the food web and an increase in discards (30 percent of total catches) pointing to an overexploitation of fish stocks beyond sustainable levels.[24]

Many fishing practices are extremely destructive to delicate habitats - particularly vital fish breeding grounds like coral reefs and seagrass meadows. Industrial bottom trawling uses large rubber tires or rollers that allow the net to pass easily over any rough surface thereby destroying the whole ecological structure; cyanide fishing to stun fish without killing them also destroys coral reef fish habitat; dynamite fishing destroys the underwater environment, and in so-called "ghost fishing" which occurs when fishing gear is lost or abandoned at sea, nets drift around and continue to catch fish, dolphins, whales, turtles, and other creatures for no reason.[30] Aside from ghost fishing, these practices may bring a short-term economic benefit, but they simultaneously destroy any economic long-term benefits. Blast fishing in Indonesia, for example, brings earnings of about US$ 15,000 / km^2 over a 20-year period but generates losses to society ranging from US$ 91,000 /km^2 to US$ 700,000 /km^2.[17]

As done in a New Zealand risk analysis,[26] impacts on the following have to be considered in any fisheries management:

- non-target species, i.e. species of commercial value captured, which are not target species;
- biodiversity, i.e. all species of non-commercial value captured but not protected or habitat-forming;
- habitat, i.e. habitats that influence fisheries or are impacted by fisheries;
- trophic interactions, i.e. indirect impacts of fishing attributable to flow-on effects on the food chain;
- protected species, i.e. species protected under legislation, specifically coral species, marine mammals, and seabirds.

Dynamite fishing is not only harmful to marine habitats and ecosystems, but also very dangerous for the fishermen themselves *© WWF-Canon / Jürgen Freund*

Marine Protected Areas support sustainable fishing

It has been shown repeatedly that Marine Protected Areas (MPAs) help to maintain biodiversity of targeted and not targeted organisms and have a positive spillover effect on adjacent fisheries:[27, 28,31]

- In Navakavu MPA in Fiji, average monthly household income (US$ 251) in January 2007 was more than double that of a non-MPA household (US$ 118).
- Since its establishment in 1995, the Apo Island MPA in the Philippines facilitated a tenfold increase in fish catch in surrounding areas.
- In Fiji, a locally managed MPA network has tripled fish catches and increased local income by 35 percent over three years.
- After 13 years of protection the densities of 11 fish species were five times higher in the Scandola Nature Reserve (Corsica) than in surrounding fished sites.
- In the Mafia Islands Reserve in Tasmania the largeness of fishes increased significantly and large fishes became more than three times more common after six years of protection.

The following testimonial is from small-scale fisheries within the West Africa Marine Ecoregion WAMER. In Cayar, approximately 60 km south of Dakar (Senegal), WWF supports a unique model of sustainable fishery management, which combines economic tools with ecological goals.[8]

“My name is Aly Ndiaye Seck. I am a fisherman and president of the fishing community of Cayar.

I want to describe my benefit from the marine resources management model of Cayar and how it has changed my day-to-day life.

Cayar is a very rich fishing ground and in the past, we caught some 30 boxes of fish, at a price of around US$ 1.5. Today, we limit the catch to 3 boxes only. That has created a certain form of shortage, and we didn’t have to wait long for the result: the price of fish skyrocketed! Today, with 3 boxes per day we negotiate prices between US$ 6 and US$ 8, and that’s just great! We could hardly believe it.

In the beginning, the traders were somewhat unhappy with receiving “less fish for more money” but quite soon, they realized they could charge more for the fish as it is larger and therefore of higher quality.

In the course of time, we have improved the management measures, but this time more in respect of a limitation of days at sea and the improvement of the security of the fishermen. For example, it is now mandatory to carry safety vests and it is prohibited to leave the port after 5 p.m.

This has really changed my personal life. I fish less, I spend less time at sea. When I leave at dawn, I’m back in the harbor at 10 a.m. In that amount of time, I can catch fish at greater value and I make more money than before. My children can now go to school, either French or Arabian.

But there are also changes in the community. Today in Cayar, there are people who switched entirely to agriculture thanks to the money they made with fishing, and with the money they had been able to save and the credit scheme that WWF had put in place.”

David Kaimowitz and Douglas Sheil argue that since for hundreds of millions of people biodiversity is about eating, staying healthy, and finding shelter, meeting these people’s basic needs should receive greater priority in the conservation agenda. “In many areas wild and semi-wild plants and animals contribute significantly to nutrition, health care, income, and culture in developing countries, and the poorest and most vulnerable people often rely most on these resources. Depleting these or making them inaccessible can impoverish these people even further.”[29]

WWF works through a global network of experts for healthy and well-managed fisheries, as well as for fishing practices that no longer negatively impact marine habitats and other marine species, just like many within the fishing industry, like Norbert Krümpelmann and Aly Ndiaye Seck, so that marine ecosystems can provide a future for their livelihoods. We promote the establishment of Marine Protected Areas all around the planet, from global to local level, as they provide a key element in the protection and long-term use of a healthy marine environment.

Marine Protected Areas protect fish stocks and biodiversity, but can also support the participation of the local community *© WWF / Papa Samba-Diouf*

Healthy oceans - healthy people

The value of such global "hot spots" of biodiversity like coral reefs is estimated to be over US$ 6.000 per hectare - with respect only to the development of drugs.[1] Up to now, thousands of new biochemicals have been discovered in marine organisms such as sponges, soft corals, molluscs, bacteria and algae, but only a small fraction of the marine organisms have even been documented.[2]

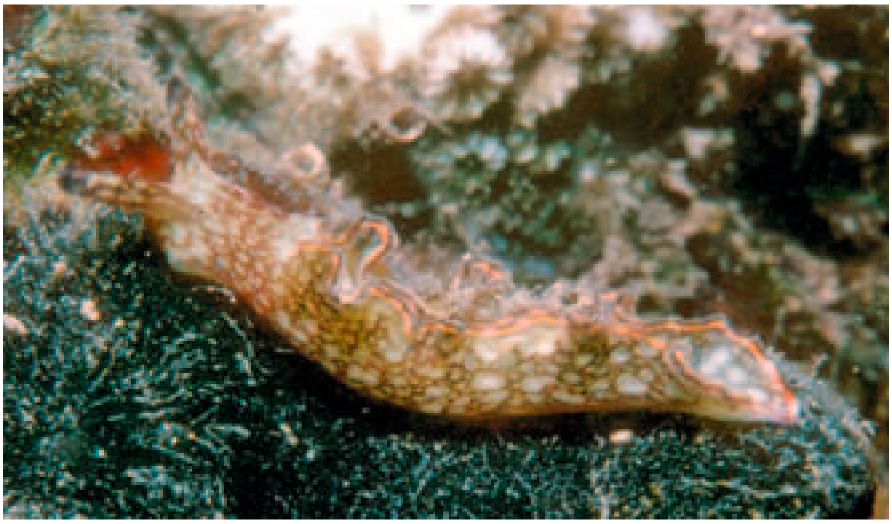
Medicine from the sea is a comparably new chapter in pharmacology. The first agents from the Carribean sponge *Tethya crypta* were discovered in the fifties, and became the base of the antiviral substance ARA-A today used in five medications to fight herpes.[3] Between 1960 and 1982 about 16,000 chemicals from marine plants and animals all around the oceans[4] were analysed for anti-cancer effects. About 30 years ago the first systematic screenings started to discover new pharmaceutical lead compounds[5], those chemical compounds in drug discovery with pharmacological or biological activity whose chemical structure is used as a starting point for chemical modifications.

The "marine pharmacology review 2003 – 2004" shows initial pharmacological results of 166 marine chemicals with:

- 67 marine organisms showing antibacterial, antifungal, antimalarial, antituberculosis or antiviral activities,
- 45 marine compounds reported to have significant effects on the cardiovascular, immune and nervous system as well as possessing anti-inflammatory effects,
- and 54 marine compounds which act on a variety of molecular targets with a potential contribution to several pharmacological classes. [6]

Marine bioprospecting is promising research: today, in fact, all new compounds from pharmacological research activities originate from the oceans – this sheds light on the potential of marine biotechnology.[5] Due to the long time span it takes to commercialise a successful product (see page 20), only four marine-based drugs are thus far on the market: Vidarabine®, the ARA-A mentioned earlier, and Cytarabine® (ARA-C), based on a compound, from the same sponge, now represent an annual market of more than US$ 50 million. AZT (Zidovudine) is manufactured under the trademark Retrovir® and was the first drug licensed for the treatment of HIV infection. [7, 8, 11] Pseudodopterosin, an anti-inflammatory agent isolated from a marine gorgonian has a market value of US$ 3-4 million per year.[13] Prialt®, the synthetic form of a compound extracted from a cone snail and approved as a treatment of chronic pain received US market application in 2005.[5] The conotoxine from the various species of cone snails alone represents more than 100 patents and patent applications.[9]

During the last decades a broad range of ‚drugs from the sea' has been researched. The following is an overview of the broad variety of marine sources and he agents they promise:



Kahalalide F, a promising anti-tumor agent, was isolated from this sea slug, Elysia rufescens, collected from Hawaii

Marine Source and organism	Agent and function	Notes
Sponge *(Petrosia contignata)*	Contignasterol anti-asthma agent, activity as histamine blockers	Starting point for semisynthetic chemicals derivative IPL576,092 shows promise as an oral asthma medication. Licensed by Aventis Pharma, in clinical trials (various phases) [18]
Bryozoan *(Bugula neritina)*	Bryostatin 1 demonstrated promising anti-cancer, anti-tumor, and immunostimulant activities	Licensed from Arizona State University for commercial development by German pharmaceutical company GPC Biotech. In Phase I/II clinical trials in U.S./Europe; U.S. National Cancer Institute (NCI) sponsored trials, price US$ 88 per 10 µg[9, 18, 20, 21]
Sea hare *(Dolabella auricularia)*	Dolastatin 10, 15 peptides are promising anti-cancer drugs showing potency against breast and liver cancers, solid tumors and some leukemias	Phase II clinical have been completed. Synthetic analogs have been successfully synthesized, some are in preclinical/clinical pipeline. NCI sponsored trials. Price US$ 125 per mg [15, 18, 20, 21]
Tunicate *(Aplidium albicans)*	Aplidine anti-cancer agent with low toxicity and a high specificity for tumor cells	First reported in a 1991 patent application. In Phase II clinical trials; licensed to PharmaMar S.A, under the trade name Aplidin® [4, 18, 20]
Gastropod *(Elysia rufescens)*	Kahalalide F gene inhibitor shows promise in treating a broad range of tumors	Completed Phase I human clinical trials in patients, and entered into Phase II trials for non-small cell lung cancer (NSCLC) and in melanoma in July 2004; licensed to PharmaMar S.A. [9, 18,20]
Coral *(Eleutherobia sp.)*	Eleutherobin tubulin interactive agent, similar to the anti-cancer drug taxol	Currently synthetic production methods are being explored, under preclinical investigation [18]
Actinomycete *(Micromonospora marina)*	Thiocoraline shows activity against several standard drug screens, including breast cancer, colon cancer, renal cancer and melanoma	Licensed to PharmaMar S.A.; is still undergoing advanced preclinical evaluation [18, 20]
Cone snail *(Conus magus)*	Ziconotide analgesic, as member of a newly described chemical family (conopeptides), very interesting as a pain management drug	Received approval in Dec. 2004 by the United States Food and Drug Administration for the treatment of intractable pain associated with cancer, AIDS and neuropathies. A synthetic version of the drug, SNX-111, is manufactured by licensee Elan Corporation under the trade name Prialt® [15, 17, 18]
Nemertine Worm *(Paranemertes peregrina, Amphiporus lactifloreus)*	Anabaseine potential as a treatment of cognitive function loss, anti-Alzheimer agent, schizophrenia	A synthetic analog, DMXBA (GTS-21) is currently under license by the Japanese pharmaceutical company Taiho and is in Phase I trials for treating Alzheimer's disease [7, 18]
Bivalve shellfish *(Spisula polynyma)*	Spisulosine (ES-285) antiproliferative (anti-tumor) agent	Natural product first reported 1999 from the commercially harvested Arctic surf clam Spisula. PharmaMar is presently directing Phase I clinical trials in Europe [18]
Sea squirt *(Trididemnum solidum)*	Didemnin B inhibit Herpes simplex viruses I and II, Rift Valley Fever virus, Venezuelan equine encephalitis virus, and yellow fever virus	The first metabolite from an ascidian to enter phase III clinical trials [16, 17]
Alga *(Portieria hornemannii)*	Halomon anti-cancer activity stated for all of the 60 cell lines of the National Cancer Institute	Component is in advanced pre-clinical studies, rapid development is confronted with scarcity and differences in quality of the resource; ongoing experiments in developing synthetic methods in the laboratory [17, 19]
Shark *(Squalus acanthias)*	Squalamin Lactat cytostatic drug, showing antibiotic, antiviral and anti-cancer activities	Discovered in 1992 as a new pharmaceutical lead, currently in phase II clinical trials for treating ovarial and lung cancer, assignee is the Children's Hospital of Pennsylvania.[15, 16, 17, 20, 21]

Commercially available are also molecular probes (for example a phosphatase inhibitor from a dinoflagellate and a bioluminescent calcium indicator from a jellyfish), orthopedic and cosmetic surgical implants from corals, molluscs and echinoderm skeletons, a diagnostic compound from a horseshoe crab, enzymes from deep-sea hydrothermal vent bacteria and others.[10] An anti-inflammatory and analgesic compound from a soft coral is now used for Estee Lauder skin care and cosmetics and is currently worth US$ 3-4 million per year.[11] Others drugs are on the cusp of commercialisation. Yondelis®, a marine compound isolated from a tunicate and now produced synthetically, will likely be finishing clinical tests in 2008/2009 and has been granted Orphan Drug designation from the European Commission and the US Food & Drug Administration for soft tissue sarcomas and ovarian cancer.[12]

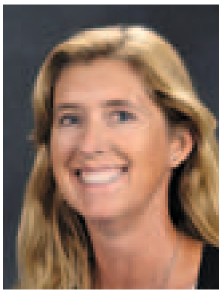
But it's a long way from a newly discovered marine compound to an approved pharmaceutical ready for commerzialisation. When a 'New Chemical Entity' is discovered, pre-clinical research starts. The compound will be screened for its bioactivity against a defined battery of cell lines and efficacy and toxic side effects will be analysed. The next step usually requires an industrial partner for further financing because several years of human clinical trials lay ahead: four phases of research on human volunteers are necessary to answer specific health questions. After successfully completing the studies the new drug application can be announced and will be proofed by the Federal Ministry before bringing it to the market. This is accompanied by post-clinical studies for the first few years to monitor for unanticipated risks or side effects. The whole process will last on average more than a decade and for every new approved therapy thousands of compounds have to be tested.[7] The direct yield from marine drugs has thus until now been relatively marginal compared to the huge potential.[5]

What are the causes of this rich variety of pharmaceutical agents in the marine world? One is the demanding living conditions connected with darkness, temperature, pressure, etc. Another reason is the immobile nature of many marine species. With limited or no possibilities to escape or defend themselves, evolution provided them with an impressive repertoire of chemical weapons to fight predators, competitors, bio-fouling, or prevent being overgrown. "Consistent with the concept of marine chemical defence, all of the new cancer drug candidates discovered are from soft bodied and vulnerable marine invertebrates."[3,23] At the same time the organisms have to retain their potency despite the dilution in the surrounding seawater.[18]

Often it is not the sponges and invertebrates being the 'real' producers of the newly discovered components, but cohabitating microorganisms like bacteria, cyanobacteria and fungi living in the extra- or intracellular tissue. Sponges in particular feature an immune system similar in some respects to the human one, and they often cohabitate with microorganisms. Research is focussing more and more on microorganisms due to their immense biodiversity and also because of the possibility of mass-producing them under laboratory conditions.[5,24]

The substance this worm, Paranemertes peregrina, uses to paralyze its prey can also serve as a treatment of Alzeimer's disease *© Harbor Branch Oceanographic Institution at Florida Atlantic University*

This coral produces an anti-cancer drug currently under preclinical investigation *© Harbor Branch Oceanographic Institution at Florida Atlantic University*



Amy Wright and her team discovered one of the most promising compounds discodermolide which was isolated from a Carribean sponge:

“My name is Amy Wright and I’m a natural products chemist and head of the Harbor Branch Oceanographic Institution in Florida

My life is very much linked to the ocean, I have been living close to the sea all my life. I started my interest in marine live by tidepooling as a kid close to my California home, and was volunteering in whale watching while at school. I analyse the chemical nature of compounds produced by marine organisms and try to discover new drugs. My team consists of scientists from fields as different as biochemistry, microbiology and cell biology to optimise drug discovery and testing. Our focus is on finding potential new therapeutics for cancer and infectious diseases, mainly from deep-water marine invertebrates and the microbes that live in association with them.

On 200 plus dives by submarine collecting sponges and other aquatic animals, I have been amazed by the diversity and beauty of deep sea organisms and the fantastic seascapes. Being a SCUBA diver I have also enjoyed colourful tropical coral reefs. I hope all this will still be there for future generations. In deeper and deep waters we luckily do not observe drastic changes. However, crossing sites were there was dredging, everything is destroyed; this is a very sad sight; the very slow growing deep coral reefs that took centuries to grow are reduced to rubble.

Scientists need to communicate their knowledge better to the public. If people know that sponges produce chemicals that may safe their lives, who would object to protect them? Consequences of environmental changes should be pictured with respect to what would change in one’s own life, that’s more convincing than an ice melt in some remote place.”

Squalamin, a substance isolated from stomach and liver of piked dogfish Squalus acanthia, shows a broad range of activities. Piked dogfish is a species considered threatened to extinction due to overfishing *© Andy Murch Elasmodiver*

There is further potential of marine diversity to contribute to medical science:[25]

- The biomimicry of marine surfaces may help to develop micro- and nano-structured implants for tissue regeneration.
- Underwater adhesion of some species may support the development of new fixation techniques.
- Coral structures and urchin spines are used in vascular graft construction and orthopedic surgical repairs because of their geometric and material properties, and coral growth and healing may improve the understanding of bone development and healing.
- Underwater self-cleaning, self-lubricating plant and animal surfaces may improve our understanding of how to help people suffering from dry eyes and mouths or people with lubricant-depleted human tissues.

In summary, the economic value of marine biotechnology can be assessed as extremely high but still in the starting blocks. As the researchers from the Harbor Branch Oceanographic Institution put it, “Marine organisms, like their terrestrial counterparts, are amazing living chemical factories, producing a collection of metabolic compounds ranging from the mundane to the miraculous”[7] and there is reason to hope that marine biodiversity will provide us with effective drugs to fight some of the most threatening diseases such as HIV, leukaemia and cancer.

Industrial resources from the sea

Marine biodiversity offers many raw materials for use in industrial production processes:

- Limestone predominantly originates from corals, molluscs, echinoderms and protozoa. Today these relics are used, among other applications, as a raw material in cement. Such species are also responsible for maintaining the global circular flow of lime.[1]
- Reef carbonates contain an estimated 40 percent of the global stock of petroleum, which also originates from marine organisms.[1]
- Diatomaceous earth (also known as diatomite, kieselgur, and celite) is a relic of fossilized diatoms, a type of hard-shelled algae. It is used principally as a filter aid but has many other applications: as an absorbent for industrial spills, for pet litter, as a filler in a variety of products from paints to dry chemicals, in insulation material, as a mild abrasive in polishes and in various other compounds. Alfred Nobel used its specific characteristics to invent dynamite. In 2007, the US production of diatomite was estimated at 830,000 tons with an estimated processed value of US$ 183 million. [2,3]

Fish meal and oil

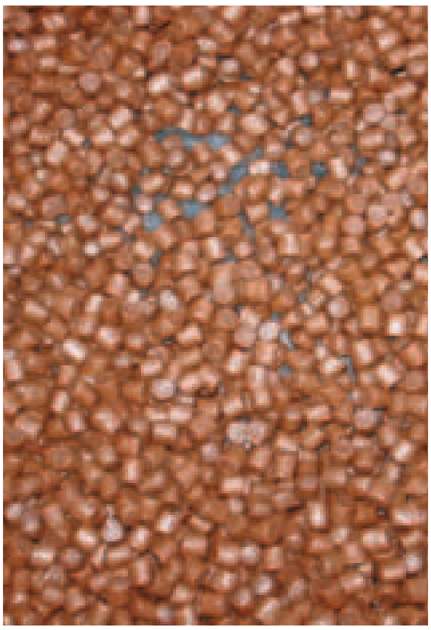
Also contemporary marine biodiversity represents an industrial resource. Not all fish caught is for food: in 2004, about 75 percent (105.6 million tons) of the estimated world fish production was used for direct human consumption while the majority of the remaining 34.8 million tons was destined for other products, in particular the manufacture of fish meal and oil.[4] In Alaska in 2001, for example, fish oil production was worth about US$ 2.6 million and the wholesale value of fish meal production was over US$ 28 million. Alaska's production of 41,700 metric tons, however, constitutes less than 1 percent of the entire world's supply.[5]

The fish oil and fish meal industry was launched in the 19th century and still represents a significant proportion of the world catch (20 percent, a portion of it being caught specifically for fish meal and oil).[6] While the unsustainable production and utilisation of fish oil and fish meal can have serious negative consequences for the environment and the oceans' food webs, it must be considered an economically important industry.

The following are actual and potential applications of fish meal and oil:[5]

- Fish oil has long been used nearly exclusively for human consumption, but due to the growth of aquacultural production most of the resource now is used for salmon farming.
- Fish meal is currently used almost exclusively for livestock and aquaculture feeds (mainly in aquaculture and the pork and poultry industries).

Fish meat and oil made into pellets for salmon farming *© Jo BENN / WWF-Canon*



- Wild capture seafood bone meal also is used for livestock feed.
- Fish waste may be converted to fish fuel comparable to diesel, with the first promising results being tested.
- Fish waste like salmon heads can be used as bait (the longline and pot fisheries consuming large volumes).
- There are a few manufacturers of fertilizer, made from Alaskan fish waste, a growing market segment.
- Fish oil, fish meal and certain organs can be used as human food, meeting dietary needs in markets throughout the world.
- The increase in pet ownership provides options for a fast growing market.
- A number of seafood products like Omega 3 oils are touted for their healthy attributes; cod liver oil is in particular a product long sought after in the markets.

The utilization of marine algae

Apart from animals, aquatic plants are being used. The use of kelp and other macro-algae has recently increased. Macro-algae (brown, red and green seaweeds) are mainly utilized for food production. Commercial harvesting and farming of seaweed was about 8 million tons in 2003, mostly in Asia. All in all, 200 species of seaweed are in use, 10 of them intensively. The world market of products from marine macro-algae has been estimated at US$ 5.5 billion to US$ 6 billion per year, with the food industry as the most important sector. Algae are used for hydrocolloids (like carrageenan, alginate and agar, used as a gelatine for cooking), and for different purposes like feed, fertilizer, chemicals, cosmetics and pharmaceutical products.[7,8] Most valuable is Nori, the thin dark seaweed wrapped around a rice ball in sushi, costing about US$ 16,000 per dry tonne.[8]

The cultivation of micro-algae, mainly for health food, is a multi-billion US$ business *© Yvonne GUEVARA / WWF-Canon*

Micro-algae or phytoplankton, e.g. *Spirulina spp.*, are used as food (health food and food supplements) and as animal and fish feed (additives and surrogates, for example in aquaculture). Some are also used for fuel production, cosmetics and as therapeutic supplements. Among these micro-algae, diatoms are the predominant form of phytoplankton and probably represent the largest group of biomass producers on earth. The market size for products made from micro-algae is estimated to be about US$ 5 billion to US$ 6 billion with nearly half being earned by the health food sector. Food supplements from marine resources include primary fatty acids, pre- and probiotics, rare and dietetic saccharides, primary and rare amino acids, dietary fibres, enzymes and vitamins. [7]

The huge diversity of micro-algae, with tens of thousands of species of which only a few hundred have been analysed, shows enormous potential for new metabolites and represents enormous markets in the future.[7] Products currently under research are biomethane and biofuel, which may gain importance with a rising awareness on climate change. Active pharmaceutical compounds, colorants, new materials, and additional polymers are also being exploited or are under development.

Seaweed aquaculture presents a special opportunity. Seaweed has been traditionally farmed in places like China, Japan, and Korea. For some countries, such as the United Republic of Tanzania, Madagascar and Mozambique, the export of dry seaweed lately has also become a source of additional income. This aquaculture is supplemental to artisanal fisheries. Seaweed farms in these countries are usually family owned businesses, with more than 80 percent being owned and/or managed by women. In Mozambique, these farms provide some 2,000 jobs and in the United Republic of Tanzania this kind of industry employs 3,000 people. Seaweed farmers are reported to earn around US$ 60 per month, greatly above the national average income.[9]

Mixed culture of fish, molluscs and seaweeds practised in the coastal bays of China has been reported as a good example by the Food and Agriculture Organization of the United Nations FAO.[9] This integrated marine farming has further proven to be highly environmentally friendly. It helps to clean the water in the coastal zone and mitigates nutrient buildup in the environment.

There are many other examples with possible economic importance: chitin and the derived chitosan from shrimps and antarctic Krill (*Euphausia superba*), for example, are traded as a raw material for cosmetics, food development, and biotechnological processes. Provided that the use of marine resources is conducted sustainably, marine biodiversity provides many resources to global industry.

Save our coasts – marine life defends the shorelines

Living marine flora and fauna play an important role in the defence of coastal regions. In many countries, especially in arid areas, the majority of people live at or in close vicinity to the coast. In Australia for example, the most densely populated percent of the continent hosts 85 percent of the population.[1]

Natural forest provide coastal protection for free, and they even regrow after a major event *© Roger LeGUEN / WWF-Canon*

Mangroves, lowland forests, barrier islands and coral reefs contribute to coastal protection. These ecosystems' ability to dissipate wave energy protects property and lives. The presence of biogenic structures on or close to the shore can reduce coastal erosion, the impact of potentially dangerous events such as tidal waves or the damage caused by storms and floods. The mitigating effects are a result of a diverse range of species binding and stabilizing sediments, thus helping to create a natural coastal defence. Even after a major event, these natural structures have the ability to recover and to regain their full functionality at no cost.

On the morning of the 26th December, 2004, an earthquake - the largest in 40 years - shook the Indian Ocean west of Sumatra and resulted in a Tsunami wave that affected the coasts of India, Sri Lanka, Indonesia, the Maldives and other countries. Some 170,000 people lost their lives and more than 1,000,000 people were left homeless. The estimated economic losses associated with the catastrophe exceeded US$ 10 billion.[2] In the time following the Tsunami, observations and later studies showed that villages with healthy mangroves, coral reefs or lowland forests suffered less from the tsunami than those that did not – or no longer do – enjoy protection by natural defences.[3,4] A study analysing 24 coastal regions in Sri Lanka affected by the Tsunami showed a significant protection by ecologically sound mangrove forests. Mangrove forests near the water's edge absorbed all the energy and were partly damaged, but the rhizomatous stem of these plants allowed new young leaves to emerge less than a month after the Tsunami impact. Other mangroves even stood firm against the ocean surge. Forests dominated by vegetative associates not typical of natural mangrove forests were, however, severely damaged.[5]

The research team of F. Dahdouh-Guebas et al. summarized, "the conversion of mangrove land into shrimp farms, tourist resorts, agricultural or urban land over the past decades, as well as destruction of coral reefs off the coast, have likely contributed significantly to the catastrophic loss of human lives and settlements during the recent Tsunami event."[5]

The monetary value of healthy ecosystems for shore protection has also been assessed: in Jamaica's Portland Bight, mangrove destruction resulted in damage to a coastal road. Here the total coastal protection value of mangroves was estimated at US$ 3.55 million in net present value terms, which translates into nearly US$ 400,000 per year.[3,4]

The value of Malaysian mangroves for storm protection and flood control only has been estimated at US$ 300,000 per km of coastline, based on the cost of replacing the mangroves with rock walls.[6] (Rock walls of course are unlikely to support the same amount of fish and crustaceans.) Protected mangrove areas in Indonesia annually contribute US$ 600 per household in terms of erosion control. Protected coral reef ecosystems around the world are valued at US$ 9 billion per year for their coastal protection. These aspects are of great importance to economically less developed countries, in particular islands.[4]

The value of coral reefs for shore protection

The value of coral reefs is manifold; their contribution to coastal protection is valued far less than for e.g. tourism. A safe shoreline, however, is an important prerequisite for tourism or fisheries and thus cannot be considered independently. Nevertheless, several attempts have been made to estimate the regional value of coral reefs.

The ability of coral reefs to buffer the coast from waves and storms varies from location to location and depends on the reef's physical shape and size. The UNEP's "in the Front Line"- report[7] estimates that a typical coral reef can absorb up to 90 percent of a wave's force, thus protecting the shore and infrastructure from erosion and damage. Studies from Sri Lanka indicate that one square kilometre of coral reef prevents 2,000 cubic metres of coastal erosion annually.[7]

A large number of studies exist which valuate the coral reef ecosystem's goods and services. A compilation of a coral cover database including more than 6,000 quantitative surveys estimates the ecosystem services to be worth US$ 23,100 to US$ 270,000 per km^2 and year.[8] For example:

- The valuation of coral reefs in the Commonwealth of the Northern Mariana Islands shows a total economic value of the reefs' shore protection of US$ 7.95 million per year.[9]
- The coral reefs of American Samoa provide benefits for coastal protection in the order of US$ 0.44 million per year.[10]
- In Guam, the total economic value for shoreline protection from Guam's reefs was estimated at US$ 84 million per year.[10]
- A very sophisticated study carried out by Lauretta Burke and colleagues estimates the economic value of shoreline protection services provided along the coastline of the Carribean islands (about 18,000 km in length). The figures range from about US$ 50,000 to over US$ 800,000 for each kilometre of coastline protected by coral reefs. The value varies with the level of development along the shoreline, population density, and presence of a tourism industry. Systemizing the shoreline into different categories, the study arrived at a total value of US$ 750 million to US$ 2.2 billion for the whole region.[11]

As with other biogenic shore protecting structures, the functionality of coral reefs largely depends on an intact ecological community. Following a massive coral bleaching event at the central granitic islands of the Seychelles in 1998, Turner and colleagues found dead standing corals only remaining in sheltered places, while exposed reefs had been reduced to rubble within two years after the bleaching.[12]

In temperate regions many types of flora and fauna also contribute to a reduction in wave energy and to the stabilisation of coastal zones.

The value of salt marshes in Germany and the United Kingdom

Sea grass and salt tolerant reeds occurring in shallow coastal waters dissipate wave energy and stabilize sediments.[13, 14] They also shelter marine meiofauna (the small invertebrates living on the sea bottom) from being washed ashore. In the UK, the major contribution to disturbance prevention comes from

The ability of reefs to protect a shoreline is reduced when coral bleaching hits a reef *© Monja Lelli / WWF-Canon*

saltmarshes, which cover approximately 45,500 ha, mainly seaward of dikes. Salt marshes and wetlands not only dissipate wave and tidal energy by 79 to 99 percent,[15, 16] they also retain vast amounts of water when inundated and slowly release it afterwards, like a giant sponge, thus preventing flooding.[17] Saltmarshes are comprised of a diverse range of species necessary to enable their flood defence function.[18]

King and Lester[5] estimated that the 80m wide saltmarsh stretch (between shore and dike land) could provide savings on costs for sea defence of US$ 0.76 million to US$ 1.42 million per hectare in capital costs, and US$ 14,182 per hectare in annual maintenance costs. From these figures Beaumont and colleagues calculated cost savings of between US$ 34 million and US$ 64 million for capital costs, and US$ 0.6 billion annual maintenance costs for the UK alone.[17, 19] The latter figure might well be doubled, since results from other studies show considerably higher values.[20]

Brouwer and colleagues conducted a meta-analysis of contingent valuation studies on wetlands from around the world. This meta-analysis found that the function of wetlands valued most is flood control. Wetlands' ability to protect from storm and flood alone is valued as US$ 211.5 per household per year[21] or US$ 464 per hectare and year.[22] The economic value of the Dutch Wadden Sea with respect to flood prevention is assessed as US$ 189 million per year,[22] compared with US$ 23.7 million Germany annually spent for maintaining the dikes and protecting the people living in the coastal area.[23]

Hans Janssen, mayor of Langeoog, describes the problem as follows:

"As a mayor I have to consider together with the federal office for coastal defence whether we should heighten the dikes or take other measures. We observe the rising sea level and the rising levels during storms. During stormy weather it is a topic of conversation on our island. And people ask me: "Mayor, what will you do to secure our island?"

We have our own water supply in the centre of the island in the Pirola Valley. But the dunes protecting the valley are substantially attacked by the sea and the beach has also become smaller. We always build up new dunes but they are far less durable. Natural dunes could grow over a long time und become settled by plants. We can roll and step as much as we want – if a big wave comes the dune will be washed away."

This may provide an impression of the economic loss if the natural coastline, with its high degree of specialized plants and animals, is to be replaced with human made structures. Renaturalisation and extensive pasturing of salt meadows can help to restore the natural shoreline protection at considerably lower costs. Katja Korff analysed the turnover of pasturing the salt meadows of the Wadden Sea National Park and found annual revenues of US$ 1.1 million, which when offset by annual maintenance costs of US$ 0.8 million in 2004, left a surplus of US$ 300,000.[24] There is multiple evidence that diverse and intact communities can cope with higher levels of disturbance and maintain or regain their functionality better than communities with reduced biodiversity.[25, 26, 27] The value of coastal protective structures can be measured in two ways:

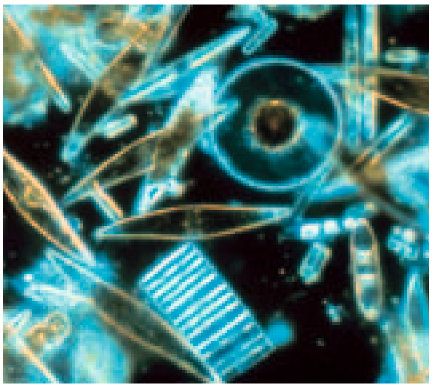
- By considering the values they are protecting:
  - the total property value of the European coastal zones was estimated at US$ 400 billion to US$ 800 billion in 2004.[28]
  - The average annual damage from floods in the United States is US$ 5.942 billion per year.[29]
- By calculating the costs of alternative protection:
  - installing artificial breakwaters made of concrete tetrapods after the degradation of the natural coral reef around the Male, Maldives, cost US$ 10 million per kilometre.
  - in Indonesia, a hotel in West Lombok has spent almost US$ 900,000 to restore its 250 metre-long beach following erosion as a result of offshore coral mining.[25]

Depending on the structure of the coast and the use of the hinterland, these values can vary greatly. Building physical barriers against the rising sea is technically difficult and expensive, especially for countries with large, low-lying coastal regions. When it comes to protecting people's lives, functioning biogenic protective structures are literally invaluable.

The 2004 Tsunami in Asia showed the importance of natural shoreline protection in the most tragic way *© Yoshi SHIMIZU / WWF-Canon*

Climate regulation

Marine systems play an important role in climate regulation, as the balance and maintenance of the chemical composition of the atmosphere and oceans are strongly influenced by marine living organisms. Of major importance here is their capacity to sequester carbon dioxide (CO_2), a potent greenhouse gas.



Microscopic diatoms use the oceans carbon during primary production and to produce their skeletons *© NOAA*

Oceanic carbon sequestration

Changes in the stratification of polar and sub-polar marine waters, which are caused by changes in water temperature and salinity, result in fluctuations of biological activity and eventually to fluctuations in the CO_2 concentration in the atmosphere. The stratification of the ocean waters acts like a 'communicating pipe' between ocean and atmosphere, and this can strongly influence climate change.[1]

It is estimated that oceans store globally around 40,000 gigatonnes (Gt) (i.e. 40,000,000,000,000 tonnes) of carbon of which 1,800 Gt are dissolved.[2] Living organisms in the ocean take up dissolved CO_2, removing it from the water, storing it in particulate matter and thereby enabling the water to further take up CO_2 from the atmosphere.

There are two general biogenic sequestering mechanisms:

- Plants, including the phytoplankton of the sea, convert CO_2 to organic matter in a process called primary production. Ocean phytoplankton is responsible for about half the global biospheric net primary production.[3] All standing stock biomass of the world's oceans are temporary carbon sinks, which means they can temporarily remove carbon from the atmosphere. Part of this biomass is consumed by larger organisms, part is remineralised by microorganisms, while the remainder sinks down to the deep sea sediments and is stored there.
- The second mechanism is biogenic calcification. The formation of heavy calcareous skeletons is a widespread phenomenon in various groups of marine planktonic organisms. Their production and – because they are weightier than water – their subsequent sinking generates a continuous rain of calcium carbonate (one component of which is CO_2) to the deep ocean and sediments. Recent models assume a rate of 0.121 Gt per year for the deep sea carbonate sink. A similarly high rate is predicted for CO_2 sequestration in shallow waters, mainly in the form of carbonate reefs and banks.[4]

Conclusion: the value of ocean climatic regulation

A recent study on the economic values of UK ocean ecosystem services determined the primary production of UK waters (i.e. carbon sequestered by phytoplankton) to be at least .07 Gt per year, which is slightly over 0.1 percent of global production.[5] To evaluate this huge amount of carbon fixing, the study takes the savings from damage avoidance to calculate the "social value" of sequestered carbon, which means that lower damage costs can be valued as an economic benefit. The carbon storage service of UK ocean waters would thus be valued at a minimum of US$ 0.85 billion to US$ 17.19 billion, taking into account primary production only. Global annual oceanic primary production can be estimated to be 55 Gt, thus the global carbon storage service is equal to at least US$ 0.66 trillion to US$13.475 trillion per year (current global Gross Domestic Product is, by comparison, US$ 60 trillion to US$ 65 trillion per year).

… and what it means for the future

Such an incredible sum may just be a gimmick with numbers. Such a sum could never be paid; moreover, the service of fixing carbon in the marine ecosystem is an existential challenge for human life which by far transcends the economic mechanisms of supply and demand. But what does this service mean for the future? We live in a relatively small 'window of opportunity' which means that the comfortable living conditions of the human species are – among other factors – bound to a specific composition of the global atmosphere. Past atmospheric CO_2 concentration fluctuated between 180 µatm in glacial and 280 µatm in interglacial periods.[6] Today's atmospheric CO_2 level has already increased to 370 µatm due to the burning of fossil fuels.[7] And without any biological activity in the ocean, atmospheric CO_2 would be 50 percent higher than it is today.[9] NASA satellite data combined with surface observations of marine plants show that the rate at which marine plant cells take up CO_2 during photosynthesis from sunlight has already declined more than 6 percent globally over the last two decades.[8]

Eternal circles of life

All chemical elements utilizable by marine organisms are continuously recycled. This is the basis for all new life and thus invaluable. While plants and bacteria take up dissolved substrates, animals need all elements in solid form. Particulate substances are re-mineralized by bacteria. There is virtually no substance on earth that cannot be degraded by bacteria. Each chemical element has its own biochemical cycle in marine systems and these cycles can vary spatially, which leads some authors to talk about different "biogeochemical provinces of the ocean".[1]

Nutrient cycles

There is considerable element flux between land, air and sea. Nutrients from land can be transported into the oceans by rivers in particular or dissolved form or by air as dust or volatiles. Oceans are generally poorer in nutrients than most terrestrial ecosystems[2], and nutrients are the limiting factors for primary production in most marine ecosystems.

Plants convert CO_2 into organic matter using solar energy. For this nutrients are utilized in certain proportions and different species have different nutrient demands and different uptake abilities. Much of the nutrients are thus stored in living organisms. Ecosystem functioning with regard to nutrients involves several processes which can be summarized as production, consumption and transfer to higher trophic levels, organic matter decomposition and nutrient regeneration.[3] The nutrient cycling function of marine systems is categorized as a supporting ecosystem service.[4]

Even though the productivity of marine systems is mostly nutrient limited the addition of nutrients – a process called eutrophication - is problematic. Fertilization of agricultural plains, deforestation and sewage production in human settlements lead to nutrient enrichment in aquatic systems. Beyond a certain limit of eutrophication the biodiversity will decline, creating conditions unfavorable for higher animals and leading to drastic simplification of food webs.[5] For example strong blooms of toxic algae are mostly attributed to eutrophication.[6, 7]

Sound ecosystems have the ability to buffer eutrophication effects within certain limits. A large number of studies have found that increasing biodiversity tends to increase biomass production[8-11] and that systems with higher biodiversity retain their functions better after eutrophication than systems with lower biodiversity.

Valuating the invaluable

Without re-mineralization nutrients would be locked in high trophic levels, thus no further primary production would be possible and thus no further aquatic life at all. In this respect, re-mineralization and nutrient cycling are indispensable for all other ecosystem services and thus invaluable. Constanza et al. nevertheless estimated the value of nutrient cycling using a replacement cost method for the valuation of the environment in its nutrient cycling capacity.[12] The values which they propose, adjusted to 2004 prices, are US$ 0.2 to US$ 0.6 per m^3. Just for the UK marine water this would equate to a replacement cost for nutrient cycling of between £ 800 billion and £ 2320 billion, to treat the entire UK waters once.[4] To replace this service, this treatment process would need to be continually repeated, so the true value would be greater.

Biodiversity is a key to ecosystem functions

In most natural systems niches of organisms overlap and multiple organisms fulfil similar functions.[13] Human influence can lead to drastic changes in the environment. Addition of nutrients or toxic substances will alter the composition of the biotic communities at all levels.[14-16] The bacterial community changes in response to available substrates[17], algal composition will respond to differences in nutrient concentrations, which will alter the species composition of herbivore zooplankton and so on through the entire food web.[3]

Too many nutrients are harmful for the environment. Algae profit from them and overgrow corals, often reducing biodiversity *© Jürgen FREUND / WWF-Canon*

Bacteria degrade oil and thus support the cleanup of oil spills *© Raúl GARCÍA / WWF-Canon*

A sea cucumber engaged in cycling nutrients *© Cat HOLLOWAY / WWF-Canon*

A decline in biodiversity is predicted to reduce the environment's capacity to respond to changing environmental conditions and to maintain ecosystem functions such as waste degradation, resulting in a decline in marine health and water quality. Microcosm experiments showed e.g. that a mixture of bacterial strains remineralized more oil faster than individual strains.[17]

Nature's detoxification services

The re-mineralization ability of microorganisms such as fungi and bacteria is indispensable also for the degradation of toxic or harmful substances, both, of anthropogenic or natural origin.

The most prominent anthropogenic marine pollutions affecting biodiversity and entire marine biosystems are oil spills. Oil is constantly released as 'produced water' and frequently leaked from offshore oil drilling installations, as well as unintended leaking from pipelines and intentional but illegal "cleaning" of vessels. Of course, the most prominent and ecologically most damaging examples are major oil spills from ship wreckages, which are comparatively rare but have discharge the largest amount and are thus most detrimental to the environment.[18]

The most important marine service with respect to oil spills is the microbial re-mineralization and thus degradation of oil. Although bacteria can only degrade a certain portion of the oil depending on various factors, they contribute to the cleanup procedures, which cost enormous sums. The most expensive oil spill in history is the Exxon Valdez (Alaska, 1989). Cleanup alone cost in the region of US$ 2.5 billion and total costs (including fines, penalties and claims settlements) have, at times been estimated at as much as US$ 7 billion. The court cases continue, however, so the final costs are not yet known.[19]

But beyond all these exercise of valuation and compensation the functional capability of these mechanisms is responsible for the possibility to economically use fish stocks, tourists attractions, pharmaceutical compounds and other all ecosystem goods and services of the marine biodiversity.

The ocean shows us how to solve problems

Bionics – a made-up word composed from biology and technics - helps us to improve our toolbox to solve problems using innovative materials, technologies and processes. Marine life provides a huge variety of examples and prototypes we can learn from. The attributes of natural materials like adaptive efficiency, multiple functions and economical use of resources are very valuable for the development of new materials. Nature shows us how composition and function can act together and how materials can emerge, transform and restore.[1]

Why is marine ecology and biodiversity so extremely helpful in this sense? A lot of characteristics of the marine environment like pressure, resistance, darkness, temperature, chemical composition etc. have stimulated evolutionary processes and lead to highly creative solutions to this adversity. Some examples:

The automobile and the sea

In automobile construction, 'bionics from the ocean' has provided valuable inspiration for innovations in research and development. Automotive lightweight constructions, fluidic optimisation, the development of particular wheel rims and tire tread patterns as well as functional profiles for bearing structures[1,9] are all technologies deriving inspiration from the ocean. Car producers, e.g. BMW, Opel or DaimlerChrysler use computer simulation programmes to learn from the growth of trees and bones how to reduce material input without losing stability.[10] The concept car "G90" of the Adam Opel AG is geared to the profile of a penguin to minimize air resistance.[11] And engineers of the BMW AG developed a new material mix composed of aluminum and magnesium which is up to 33 percent lighter than aluminum. The two substances are combined using the anchor principle of venomous cells of jellyfishes and sea anemones.[12] By using the material mix in a new six-cylinder motor they achieve a net weight benefit of about 10 kilograms. There has been an increasing number of special symposia dealing with 'bionic principles in automotive construction'.

The Mercedes-Benz bionic car[13]

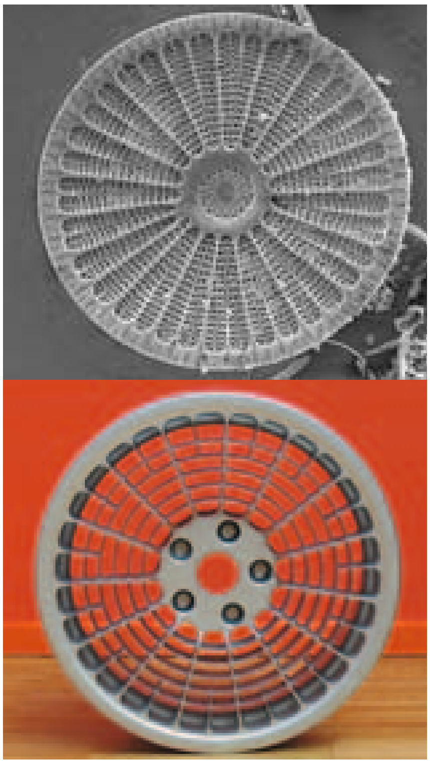
In June 2005 the Daimler AG presented the first 'Mercedes-Benz bionic car' at its Innovation Symposium in Washington. The car is a unique research project by engineers and has been modelled on the boxfish. Boxfish live in structured habitats like tropical coral reefs, lagoons and seaweed and thus need attributes like a modern car: body protection and a good manoeuvrability combined with power and streamline.

The living model contributed various features to the Mercedes-Benz bionic car. One is the exceptional aerodynamics efficiency with a Cd value of 0.19 which has been translated into a form which should reflect the typical Mercedes criteria.

Prototype in nature	… and how it is used
The form of the snout of a dolphin	… inspired a similar bulbous bow for oil-tankers which helps to save fuel by up to 10 percent.[2]
The wavy newel form of a penguin	… will be used as a benchmark for the design of submarines.[3]
The extremely hard and break-proof nacre as well as the teeth of sea urchins	… gave the impulse for an innovative way to develop tough ceramics as foils, membranes, scaffolding structures and high-textured coatings.[1]
The stable and sophisticated forms of diatoms	… have been copied to design lampshades and computer cases[3]
The configuration of the fibres within the sponge *Euplectella*	… has successfully been used as a prototype for architectural constructions.[5]
The lateral line (organ) of fishes	… can also improve the manoeuvrability of submarine vehicles and has been copied with capillary hairs made from silicon.[6]
The communication strategies of dolphins	… have been copied to create a pattern of sound waves able to bridge wide distances.[6]
The navigation of lobsters	… has been copied to develop a 'robolobster' which shall be able to locate mines or leakages in pipelines.[7]

The boxfish has inspired developers shaping a Mercedes… *© Daimler AG*

Another attribute is the firm but lightweight construction concept of the boxfish's outer skin made of bony, hexagonal plates and its internal bone structures that are reflected in the bodywork of the car.
The Mercedes-Benz bionic car is the very first example of a complete transfer from nature to technology: the researchers and engineers at the Mercedes-Benz Technology Center (MTC) looked for an example in nature with a combined shape and structure approximating their ideas for an energy efficient (aerodynamic, lightweight), manoeuvrable, safe and spacious car.



… while these wheel rims were designed adapting the structure of a diatom skeleton
©Alfred-Wegener-Institut/ Friedel Hinz

Wheel rims like diatoms

Skeletons of diatoms imparted new insights into the lightweight construction principles of rotating components.[14] Here, nature offers a rich variety of filigree designed yet very stable forms. The 'Friedrich Hustedt Study Centre for Diatoms' at the Alfred Wegener Institute provides a database of complex, species-specific patterns of the silica structures supporting the cell-walls . They can serve as models and challenges for architects and product designers. The working group of Christian Hamm at the Alfred Wegener Institute designed very lightweight but stable wheel rims using diatom models.[3]

Squids and octopuses demonstrate how to use the light

Diving down into the sea darkness soon grows, and marine biodiversity has invented tools and adaptations to work here with the scarcity of daylight. Squids and octopuses especially present some promising examples for human technology:

- A family of unusual proteins acts as reflectors for a bioluminescent light the squid uses as a spotlight. These squid proteins are thought to be unique among animals, report Wendy Crookes and colleagues. [18] Squids use these proteins to perfect their camouflage.[19] These reflector proteins are the first optical nanostructures based in protein, and they offer hope for use in optical fibres or processes of human-made photosynthesis.
- The eye of an octopus is able to bundle the light five times better than the human eye. Researchers dealing with material used construction principles of the octopus eye to develop an extremely sharp-sighted lens which is considerably lighter, cheaper and less damageable than the usual lens made from glass. Eric Baer and colleagues piled up hundreds of thousands of super-thin synthetic sheets having different indices of refraction. With this kind of marine-inspired nanotechnology he has been able to develop an artificial eye showing very promising properties for different fields of application including construction of new eyeglasses.[20,21]

Mussel glue for medical treatments

Marine species such as barnacles or common mussels show a very strong adhesive power. They can be used to help to develop a biomimetic glue which can harden underwater.[22,23]

"The common mussel is a true master of adhesive bonding. Mussels stick fast not only to iron, wood and stone, but also to panes of glass, painted surfaces and Teflon coatings", Fraunhofer scientists noted. "Neither brute force nor wind and weather can break this bond. These molluscs can hold onto walls and posts by their adhesive threads for years, even when pounded by mighty salt-water waves and surf."[25] Even in a damp environment, where other adhesives fail, the mussel secretion can be relied on to stay put. That is why it is ideal for medical and technical applications.

The researcher Ingo Grunwald from the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) in Bremen was asked to observe the phenomenon during holidays in Denmark.[24] He reports:

"The focus of our work at the IFAM is the use and further development of technologies that underwater life has evolved – things like antifreeze mechanisms by arctic fishes or mussels' glue.

During my last family holiday in Denmark I had a chance to combine my vacation with my work. The weather had been rather bad so we started some experiments with mussels we had collected at the beach and stored in a small basin in front of our cottage.

We watched them stick to the basin edge and observed how they moved their foot and started to climb the wall. Then together with the children, I took household articles from the cottage and tested their adhesive power. The mussels adhered everywhere – to knives, forks and spoons, to oil-daubed pots, to new ceramic plates, to CDs, and even to a Teflon-coated pan. Currently, no existing glue is able to do this.

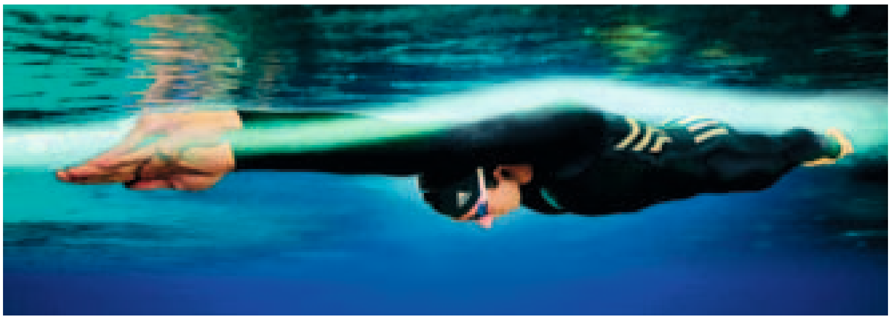
The mussel adhesive protein is a miraculous material. It is soft and hard at the same time and is able to connect the flexible tissue of the mussel with the hard stone of a wave-breaker, and this bonding buffers the power of the waves. It has all the features we want to obtain.

These characteristics are known and the adhesive protein of the mussels is already in use in microscopy to fix tissue preparations on microscope slides. But one milligram of mussels' glue costs about US$ 316, – while one milligram of gold only costs 32 cents – and about 10,000 mussels are needed to produce one gram of the material.

During this holiday research with my family, I began to see a whole range of potential applications of the mussel glue. After our experiments we tried to clean all the dishes but not even the dishwasher with its power program was able to remove the glue dots. We had to scrape the mussels' secretion off by hand. After the mussels had made their contribution to scientific progress, we decolonised them again. In the meantime we now have an aquarium in our lab where all our visitors can marvel at the mussels gluing around."

Mussel's can stick to almost every surface like this CD. The mussel glue may be important in medice, as it is well tolerated by the human body *© Ingo Grunwald*

Potential areas of application of the mussel glue are the dressing of wounds, fixing of broken bones, serving as a fixative aid for ligaments or dental prostheses or repairs of the retina. The mussel adhesive is well tolerated by the body. Until now, it has had to be extracted naturally which means it is very expensive. Researchers are currently reproducing a synthetic version of the secretion to pave the way for its industrial production.[25]



The very low friction of shark skin's rough surface gives high performance swim suits a critical advantage *© Cat HOLLOWAY / WWF-Canon,* *© adidas AG*

A gold medal for shark skin

The rough-textured skin of the shark is the prototype for different inventions. It has provided insight into how to protect a ship's hull from adherent organisms like barnacles (which reduce the speed of ships and increase fuel consumption) and thus prevent the use of toxic protective coatings.[24] In the same way it has modelled how to diminish the aerodynamic drag on moving bodies. The Airbus A320 / A340, for example, is laminated with a so-called 'Riblet Foil' which reduces air friction losses by up to 8 percent and can save 2.4 tons of fuel per long-distance flight.[15,26] With the JetConcept body suits from adidas or Speedo,[22] the surface friction is reduced by microscopic teeth which cause a suppression of eddy formations. Thanks to the small integrated riblets, inspired by rough textured shark's skin, the JetConcept reduces the drag a swimmer faces in the water. From the available research it is unclear to which degree the bodysuit measurably assists the swimmer because the improvement depends on body and style and is difficult to measure. But the results are impressive: Ian Thorpe, the first swimmer to ever wear this suit, won two gold medals, one silver medal and one bronze medal at the FINA World Swimming Championships in Barcelona and praised the revolutionary swim suit.[27,28]

Marcus Kürner, Senior Environmental Manager with the adidas AG, comments:

"The ecosystem Earth is not only the world in which we live: its biodiversity is a source of highly creative ideas, solutions and transformations from which humans have much to learn.

Inspired by nature's example of the lotus effect, and by new marine studies on the structure of the shark's skin with its flow-enhancing design, the creative inventors of the adidas AG developed a synthetic full body swimsuit for top athletes.

Biodiversity and nature protection not only secure our living space but also maintain the often under-explored treasure of data and ideas of the earth."

Some of these examples are prototypes for new materials, often connected with nanotechnological development. Others represent new designs adapted for special living conditions. All of them - and many more in future – illustrate the inspiring nature of a highly diverse marine biodiversity.

How should a parasite value its host?

… that is the subtitle of a publication from the scientist William Rees, one of the originators of the 'ecological footprint'- concept.[0] With this study we try to highlight the quantification of goods and services of marine biodiversity and ecosystems, a process that is called economic valuation. As shown at the beginning there are a lot of restrictions in doing so and the question arises why such an exercise should be done.

As ecosystem services cannot be fully ‚captured' in commercial markets or adequately quantified in economic terms, they are often given too little weight in political decisions making. Hence we try to at least show the magnitude and variety of economic values connected with marine ecosystems, to make the range of potential values more apparent and to demonstrate the importance of healthy oceans to mankind, for a wide spectrum of even economic reasons.

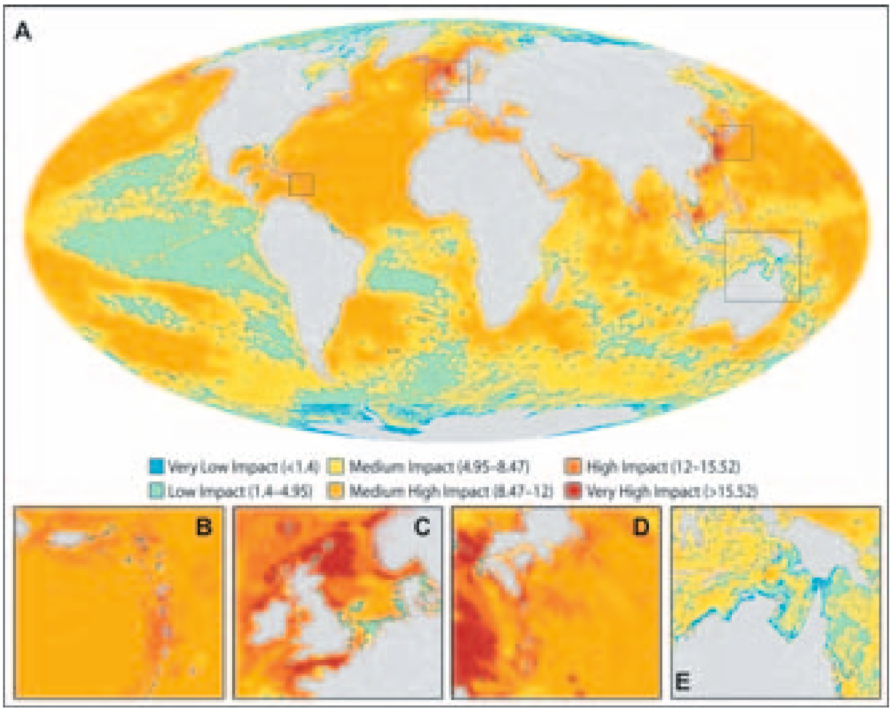
Economic valuation demonstrates the relative importance of economic activities and how they depend on the marine biodiversity, and therefore we hope to clarify further the importance of conservation activities.[1,2]

We accept conceptual and methodological problems of 'spotlighting' a very complex topic which in fact is currently the subject of vigorous debates between experts discussing proper methodologies and the sense of such valuation as a whole.[3,4] In practice, the valuation of marine biodiversity and ecosystems' goods and services includes some of the oldest problems in economics: revealing and aggregating preferences ("which state is favourable for me?") and addressing uncertainty ("what development can and should be reached?").[6,7] Results of valuation studies can differ widely according to e.g. the local income situation, the cultural context, the degree of information or alternatives presented to questioned people and also to the scientific methodology used for the analysis influences significantly the figures resulting from the analysis.

Valuation studies of ecological goods and services also cannot fully take into account the problem of public goods which partly are not tradable and can be used by everyone[8] - this is especially an important problem for the marine environment which often is confronted with unclear property rights and political responsibilities:
So a lot of studies valuating the non-market environmental goods and services exist for specific analytic or policy purposes and are related to specific countries – which also means that the marine biodiversity often is not included because it is not seen as part of a specific country.[9] Additional complications are caused by the extreme complexity resulting from significant limitations in current scientific knowledge of the effects of marine biodiversity on ecosystem functioning.[10]

And last but not least the utilitarian value reflecting the "implicit metaphor of earth as a welfare- producing machine"[11] has to be counterbalanced by non-utilitarian values derived from a broad variety of ethical, cultural, religious and philosophical bases.[4,12] Spiritual and cultural values are the intangible benefits of protected areas but they are difficult to quantify in economic terms.[13]

Global map (A) of cumulative human impact across 20 ocean ecosystem types. Highly impacted regions in the Eastern Caribbean (B), the North Sea (C), and the Japanese waters (D) and one of the least impacted regions, in northern Australia and the Torres Strait (E).[14]



In one of the most famous marine symbioses, a sea anenome provides this clownfish with the basic, valuable services of food and shelter. *© Cat HOLLOWAY / WWF-Canon*

But in spite of all these restriction we attach importance to this type of valuation studies. As Daily and colleagues argue,[6] "valuation is a way of organizing information to help guide decisions, but not a solution or end in itself. It is one tool in the much larger politic of decision-making. Wielded together with financial instruments and institutional arrangements that allow individuals to capture the value of ecosystem assets, however, the process of valuation can lead to profoundly favourable effects."

With this study we can show the importance of marine biodiversity even from an economic point of view. But in spite of these facts the status of protection of the marine biodiversity is still alarmingly low. All marine areas have been shown to be affected by human influence and a large fraction (41 percent) is strongly affected by multiple drivers.[14]

Currently only 0.6 percent of the world's oceans have been designated as Marine Protected Areas (MPAs) - compared to almost 13 percent of our planet's land area - and the vast majority suffer from little or no management at all. [15] The situation is even worse for marine waters beyond national jurisdiction, where hardly any MPA exists to protect fish stocks or conserve marine biodiversity and the 'global marine commons'.[13]

Balmford and colleagues made a survey on 83 running MPAs worldwide questioning the actual and needed annual expenditure and assessed the economic value. They came to the result that a „global system of marine protected areas... meeting the World Parks Congress target of conserving 20-30 percent of the world's seas might cost between US$ 5 billion and US$ 19 billion annually to run (…) and could itself directly provide around one million fulltime jobs in MPA protection, almost certainly more than are maintained by all fishing subsidies worldwide."[16] Comparing this figure with Constanza's estimated value of global marine systems of US$ 20.9 trillion – as contended as it may be – and moreover having in mind the oceans' further values as addressed above, particularly their importance as a food source, we strongly believe that an acceleration of global efforts to reverse the trend of ongoing degradation of the marine environment will pay off greatly for mankind.

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