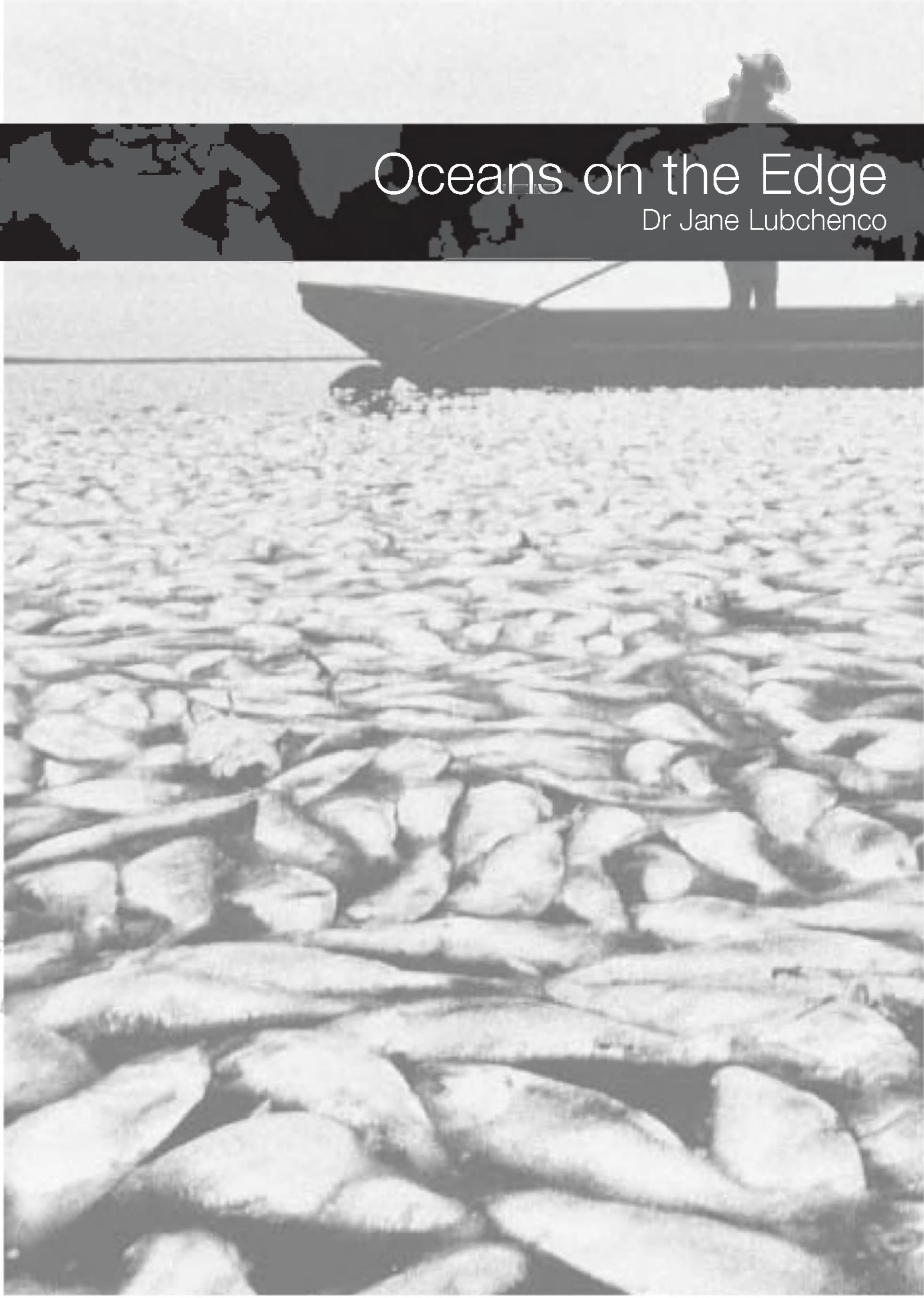
Oceans on the Edge

Dr Jane Lubchenco



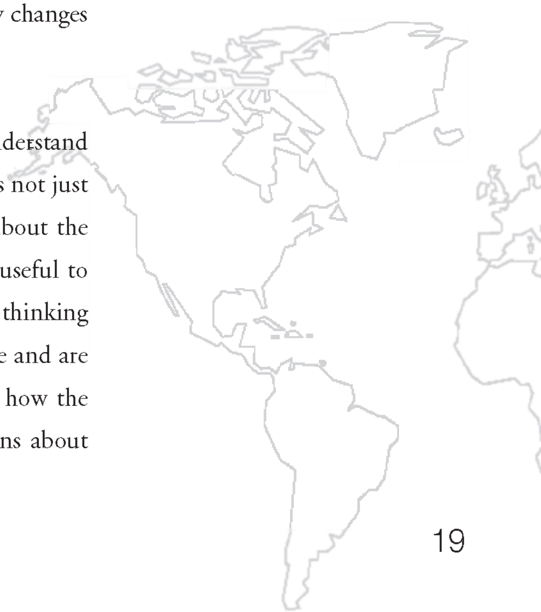
The aspect of the environment I am concerned with is the oceans, but I will begin with the role of science: both its broad role in today's world and its more specific role as we learn about changes in the oceans and consider how to respond to them. Then I want to set a broader stage for the global context and global changes that are under way. What is happening in the oceans is also, of course, happening on a larger scale, and we need to start with this big scale, then move to the only slightly smaller scale of oceans. Lastly I will discuss oceans at risk, the scientific knowledge we have about what is changing, the possible solutions, the choices that we have as individual citizens and as institutions, and the future.

The role of science

If you ask politicians around the world about the historical role of science, they usually focus on the economic or health benefits of investing in it, or on how it improves people's lives generally – extremely important reasons to invest in science and for citizens to value it.

Science has other roles in today's world which are not as commonly appreciated, in informing and helping us to understand, particularly with regard to change. Science plays a critical role in documenting changes that are happening, providing a neutral source of information that goes beyond assertions or observations that might just be correlations, and providing some historical records. From these we can gain information about whether an event represents a new development or whether it is something that just comes and goes. This is extremely important, as is understanding the consequences of any changes in light of how natural systems, social systems or natural-social systems operate and interact.

We can use our knowledge of how the Earth system and the climate system work to understand any changes that are occurring and to interpret their consequences. A critical role of science is not just to understand the past and the present but also to help us think about and make choices about the options in front of us, and their possible outcomes. In choosing to take Path A or B, it is useful to know the likely results of those decisions. So a hugely important role of science is to inform thinking about the trade-offs created by our choices – realizing that we do not have perfect knowledge and are looking ahead – grounded in our understanding of the changes that are happening and of how the systems work. And, finally, it is critically important for science to be part of the discussions about possible solutions to problems.



Global changes and their consequences

A few years ago, some colleagues and I published a paper in *Science*. We wanted to take a broad look at the global-scale changes for which there is valid scientific information published in the literature, and get away from any assertions that were being made about changes that might or might not be happening. Those we identified, ones which nobody much argues about, can help us gain a sense of some of the important global-scale changes that are under way and, in particular, the magnitude of the human contribution. The changes related to: climate, land use, biochemical cycles, water use, biodiversity and fishing.

Most of the changes directly caused by human activity have happened within the last 100 to 1,000 years. We know, for example, that humans have transformed about half of the Earth's land surface. That is a considerable amount, and most has happened relatively recently, mainly over the last 200 years. We also know that our activities have increased the carbon dioxide concentration of the atmosphere by 30 per cent since the beginning of the industrial revolution. We know that humans currently utilize about half of the available surface freshwater on the planet. We know that humans are responsible for about half of the nitrogen that is fixed on an annual basis, so we are modifying one of the major biochemical cycles of the planet by more than doubling annual nitrogen fixation. We know that we are moving invasive species around the planet. (As a non-global example, about 20 per cent of the species now in Canada are invasive.) We know that about a quarter of bird species have become extinct in the last 1,000 years, due directly or indirectly to human activities. And we know that two-thirds of the major marine fisheries are fully exploited, overexploited or depleted.

This gives us a starting point for saying that there is a broad sweep of environmental changes under way. The current time is different from any other in the history of Earth because of this footprint of human activity, and the consequences are multiple and complex. Put very simply, however, these changes taken together – climate, land transformation, disrupted biochemical cycles, water use, biodiversity and overfishing – are altering the functioning of the ecological systems of our planet, whether forests, coral reefs, wetlands or grasslands, and are in turn changing the delivery of ecosystem services to humanity.

Ecosystem services are the benefits that people receive from the functioning of intact ecological systems. The Millennium Ecosystem Assessment is a critically important new global evaluation of the status of ecosystems and how they relate to human well-being. It categorizes ecosystem services in four general areas: provisioning services (food, water purification as it is filtered through an old-growth forest or a wetland, fuel); regulating services (climate, disease); cultural services (spiritual, inspirational, recreational, heritage, education); and supporting services (the ones that are critically important to providing those in the first three categories). The global-scale changes that are under way are modifying ecological systems and their functioning, which in turn impairs the delivery of many of these critical services. It is this connection between change, ecosystem functioning, ecosystem services and human well-being that focuses our concern on the changes that are taking place.

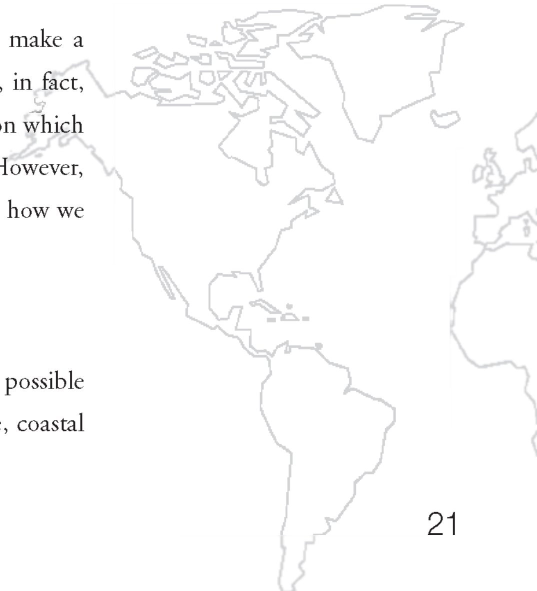
Loss of services has direct and indirect consequences for human well-being, and much of this is being explored in the Millennium Ecosystem Assessment. Put very simply, the connections to human well-being are very basic. Ecosystem services affect human health, basic materials for a good life, the security of people, social relations, freedom and choices.

Clearly, many different things are driving the changes that are under way, and it is this diversity and complexity that makes altering any of them a very daunting task. Nonetheless, the more information we have about the drivers of change, the consequences of change and how they affect people directly, the better position we are in to make informed choices and to try to redirect the changes.

Humanity is faced with a grand challenge unique to our time, and this is simply to make a transition to a world in which everyone's basic needs are met without compromising – and, in fact, while protecting and restoring – ecosystems and their ability to deliver the critical services upon which all life depends. That is a huge task, and it is one that we do not quite know how to go about. However, understanding the connections is a critical link in thinking through what the choices are and how we might do things differently.

Oceans at risk

I am going to turn now to ocean changes and their consequences, and some of the choices and possible solutions in front of us, concentrating particularly on four aspects: fisheries, climate change, coastal development and pollution.



Fishing is the single activity with the largest impact on ocean ecosystems today. We know that global fisheries, which were on a spectacular rise in terms of total landings throughout the last century, peaked in the 1980s and are now slowly but steadily declining. Thus, 67 per cent of global fisheries are now fully exploited, overexploited or depleted, according to UN Food and Agriculture Organization (FAO) categories. It is particularly sobering to think that this 67 per cent was only 5 per cent 40 years ago.

FAO data give a temporal sense of some of the changes. About midway through the last century, around half of fisheries were in an underdeveloped stage, but by 1970 there were none in this category. The second half of the century saw an increase in the number of fisheries in the mature or senescent stages.

Such dramatic changes in a short period of time are due to our technological capabilities to find, catch, preserve and deliver fish and seafood at rates which were formerly simply not possible. A paper by Myers and Worm, published in *Nature* in 2003, provided the startling information that about 90 per cent of the really big fish – tuna, swordfish, marlin, sharks, those icons of the oceans – have gone. Within 10 to 15 years of an industrial fishery getting under way, and before good baseline information has been taken, much of the fishery in terms of these large species is lost. So the oceans today are significantly depopulated.

Off the coasts of Oregon, we have seen a situation typical of many places around the world. We are all familiar with cod numbers, but we can also look at figures for landings of rockfish off the US west coast over the last few decades. Early on, there was a significant increase in landings and then, as is typical, an abrupt decline. There were serious pressures to continue fishing and a lack of appreciation of the fact that many rockfish are slow growing, long lived and not able to reproduce at the rate originally thought. A number of specific species of rockfish which used to be relatively abundant became so overfished that the largest fishery closure ever in the entire world was declared in 2002 – 8,000 square miles off the west coast of the United States is now closed to groundfish fishing because of the depleted nature of these stocks.

Not only do these kinds of changes disrupt marine ecosystems and specific populations, they also have significant economic and social consequences. In addition to fishery collapses and crashes, the removal of biomass from the oceans results in a number of unintended outcomes, ones that we need

to understand in order to manage fisheries better. It is these factors which collectively have had such a huge impact on marine ecosystems.

First and foremost, the removal of top predators has huge consequences. Many are keystone species, apex predators. Removing them triggers cascading changes throughout the ecological system. Some kinds of fishing activities significantly alter habitat – dredging and trawling, in particular, are among the more destructive, eroding the sea floor and, in many cases, destroying very long-lived, three-dimensional structures that provide nursery areas for fish. This compounding influence makes it difficult for fisheries to recover after the habitat has been altered so significantly. By-catch – the incidental take affecting anything from other fish to turtles, marine mammals or birds – is a significant problem and often serious. It alters the size, age structure and sex ratios of the target species.

All these factors are beginning to be better understood and need to be incorporated into fisheries management. This is one of the reasons for thinking about ecosystem-based management, not just management of individual species, individual targets or clusters of similar species.

Many people think that with the oceans so depleted, fish and shellfish farming will solve the problem. In fact, the fastest-growing segments in the food production industry – salmon, shrimp and other carnivorous species of fish – depend very critically on wild-caught fish made into fishmeal, and the conversion ratios are such that continuing to catch small pelagic fish to rear salmon, shrimp, cod and so on is contributing to the depletion of wild cod species, not just relieving pressure on wild cod fisheries. Food production is critically important for the future, and we need to think how to do it more sustainably than at present. Current pressures are pushing it in an unsustainable direction, so we face a huge challenge.

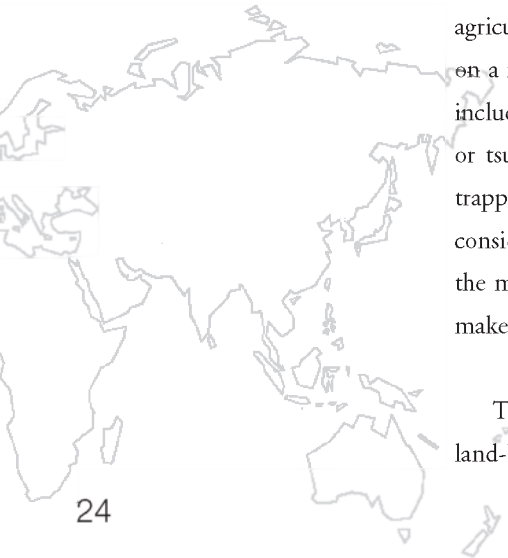
Climate change is another phenomenon with enormous ramifications for ocean ecosystems. It is not only the temperature of the water and of the air that is changing. Increased water temperature affects coral reefs, for example, and we have seen significant bleaching and increases in bleaching events throughout the tropics. Rising sea levels also influence the erosion of coastal areas. And we are seeing some unanticipated and possibly very important changes in the pH of oceans. Much of the increased carbon dioxide has been absorbed by the ocean and that, in turn, will be likely to affect the rates at which corals and many phytoplankton can build their skeletons, and will impact other shell creatures in the oceans, from mussels, scallops and clams to snails. Anything that has a calcium carbonate shell is affected by the pH in oceans.

Climate change is also likely to affect the intensity of coastal upwelling – areas where many of the major fisheries are located. Upwelling is driven by winds that are a function of the difference between the temperature of the land and the temperature of the water, so as we change those temperatures, we are altering the intensity of the winds and the intensity of upwelling. These are some of the many changes that we are only beginning to be aware of with respect to how climate is affecting oceans and ocean ecosystems.

About half of the world's population lives in coastal areas, and the proportion is increasing as more and more people move to the coast. Coastal development is happening at a frantic pace, is usually based on local decisions and has very serious consequences for coastal marine ecosystems. It affects the flow of water, nutrients and sediment to the ocean, and it changes the chemistry of the atmosphere and habitat for coastal species.

One example occurs with mangroves, a critically important habitat in coastal areas around the world. About half the world's mangroves have been converted to land for human settlements or agriculture, or for shrimp ponds – an example of land transformation. For mangroves it is happening on a massive scale with wide-ranging effects. As the mangrove is transformed its ecosystem services – including the provision of fish nursery areas, the provision of food, buffering of shores against waves or tsunami, detoxification of pollutants as they come from the land and flow into the ocean, and trapping of sediments so that they do not smother downstream coral reefs – are lost. There are considerable trade-offs to be considered in balancing the pros and cons of coastal developments, and the more information we have to enable us to understand these trade-offs, the better able we are to make appropriate choices.

The last factor that is having a strong influence on coastal oceans, in particular, is a result of land-based activities and has to do with nutrient pollution. Nitrogen is the primary factor in this, but



there is an element of phosphorus as well. The nitrogen in the atmosphere is not in a form that can be utilized by plants; it has to be chemically changed or fixed. Naturally – before or without humans – about 100 teragrams of nitrogen are fixed globally on an annual basis on the land by natural sources (algae and bacteria, a little bit by lightning). Over the last century, this figure has more than doubled because we are making fertilizers, planting legumes over a larger area than they would occupy naturally, and burning fossil fuels, with fixed nitrogen as one of the unintended by-products. This huge amount of nitrogen resulting from land-based activities ends up either flowing off agricultural areas, via rivers and streams, into coastal zones, or being transported by the air and deposited in the oceans.

The flow of nitrogen and phosphorus to coastal areas is having a significant impact and disrupting marine ecosystems, especially in coastal waters. As a result, two things are happening. First, we are seeing "dead zones", which are essentially the result of a bloom of phytoplankton. The herbivores in the system cannot keep up with the phytoplankton, the phytoplankton die and begin to decompose, and that uses up all the oxygen. In the United States for example, much of the nitrogen used in the Mississippi drainage basin to grow corn and soybean as cash crops is being deposited in the Gulf of Mexico. At the mouth of the Mississippi river, there is a zone of low oxygen, or hypoxia, which is growing larger and larger each year and is now about the size of the state of Massachusetts.

These are global effects. There are around 50 hypoxic zones around the world, most of which have appeared in the last 30 to 40 years, and most of which are at the mouths of areas that drain major agricultural areas.

Another outcome of nutrient pollution is the stimulation of certain types of plankton which contain toxins or are otherwise harmful. We are seeing more and more harmful algal blooms around the world, some of which can cause massive death of fish as well as affect human health.

It is sobering to look at these different effects. The oceans are changing at unprecedented rates, the complex result of multiple factors. There is no one silver bullet: it is not just climate, it is not just commercial fishing, it is not just recreational fishing, it is not just agriculture. It is all those things together, acting in concert and often exacerbating one another. This presents an enormous challenge.

Part of the reason this is occurring is because we have not been tracking what is happening, or paying it much attention. Most citizens are not aware of the changes; most political leaders are unaware of most of them, or if they are aware there is no set of solutions available; and there are vested interests promoting business as usual.

Possible solutions and choices for the future

Let us turn to the choices that are available and some of the solutions that are being explored. I have divided the choices into those for which the scientists have been actively engaged in providing new understanding, those on which governments are working, and those on which citizens' groups are concentrating.

We will start with two areas where science is providing possible solutions. One is trying to understand large marine ecosystems and how they work. There is increased talk about ecosystem-based management, but we have never really studied ocean ecosystems at that scale. On land, there are studies of forest ecosystems, wetlands and grasslands, but the infrastructural and technical capabilities to properly study ecosystems in the oceans have not been available.

There are some 64 large marine ecosystems around the world. The one I will focus on is the California Current Large Marine Ecosystem off the west coast of the United States. This is formed by an oceanographic current that comes across the Pacific and splits into two when it hits Vancouver Island, Washington. One part, the Alaska Current, goes north while the California Current goes south to define a large marine ecosystem. It is at this scale that we need to be thinking, in part because a current transports larvae throughout that system and a wide variety of creatures move around in it. Even though it has not actually got a fence around it, it is a cohesive ecological unit that needs to be better understood. PISCO (the Partnership for Interdisciplinary Studies of Coastal Oceans) is a new model for the study of large marine ecosystems, and there are various study sites up and down the coast focusing on the nearshore portion of this one.

Typically, the study of ecosystems, particularly in the United States, has been very atomized. We have different bodies – such as the National Science Foundation (NSF) or the other government foundations – funding oceanography on the one hand and marine ecology on the other. There are different groups that fund fisheries, or economics, or disease, or sociology. This atomized approach is beginning to change, but it has been the historical pattern.

It has been very difficult to conduct integrated studies that are interdisciplinary or cover more than just a couple of years, the duration of most NSF grants. The PISCO research programme is designed to be very different: to be long term, to integrate across many different disciplines, to be responsive to management needs and to have fundamental links to policy.

It involves four different universities along the west coast, and the principal investigators at each university have agreed to use uniform ways of carrying out research and monitoring. We are all collecting data in the same way up and down this coastline: data for oceanographic information, physiological information (looking at genetics and biological physiology), ecological information, policy and management.

The idea is to understand the dynamics of the large marine ecosystem, focusing on that nearshore ocean. This has historically been a no-man's area – ocean-going vessels are too large to come in close to shore, and marine ecologists only stand on the shore or perhaps dive in kelp forests – and we are working to integrate the nearshore ocean, the area that actually bears the brunt of both ocean-based activities such as fishing, mining and drilling, and land-based activities that are impacting the area. There will be an intense focus on this nearshore ocean, both for research and monitoring, and for training students in an interdisciplinary manner, as well as providing information for policy and management.

We are excited about what we are doing. It is a challenge to keep up with all the new findings, and I think we are going to be seeing some very remarkable progress in building the knowledge base to help inform ecosystem-based management.

I want to turn now to some of the scientific programmes that concentrate on understanding what many have suggested is the most powerful new tool at our disposal to help recover the bounty that has been lost from the oceans – marine reserves. A marine reserve is an area of ocean that is fully protected from destructive or extractive activities on a permanent basis, except as needed for evaluation or monitoring. These are "no-take" areas. Marine reserves are not a new concept but one we have had little information about until relatively recently.

A marine reserve is not the same as a marine protected area. A marine protected area is managed for some conservation purpose. It might prevent drilling for gas and oil but allow everything else. It might not allow fishing for a particular species but allows other fishing. At the furthest end of the spectrum in terms of restricted areas are marine reserves, and it is this type of management that is going to have the most benefit, though of course marine reserves have to be part of a larger context of marine protected areas and better management.

The kinds of questions asked about both marine protected areas and marine reserves are: where should we put them, how big, how many, what are the trade-offs if we are closing areas to fishing; and do they work?

A working group on the science of marine reserves operated for about three years out of the National Center for Ecological Analysis and Synthesis in Santa Barbara, California, an interdisciplinary group of scientists from around the world. It resulted in a number of products both for scientists and for the public: a special issue of *Ecological Applications* and a series of papers and journals. Some of the results relate directly to our topic here, particularly what happens inside and outside the reserve as well as network design. We made a comprehensive analysis of changes when an area becomes a marine reserve, using studies and data from more than 100 reserves examined and 80 analysed, representing about 23 nations. I want to emphasize that the total area of all the marine reserves in the world adds up to far less than 1 per cent of the surface area of the ocean – just a drop in the bucket.

The analysis showed what happens to key biological measures – biomass, density, size and diversity – in terms of percentage increases. Generally there is a huge increase in biomass because there is no fishing and nothing is removed. There is a huge increase in density and a significant increase in average individual size and diversity. Reserves vary considerably one to another but, in general, species are more abundant, more diverse and larger inside reserves, and they reproduce more. Reserves also protect habitats. In the oceans there are many kinds of habitat – sandy, rocky, ridge, boulder, the sea floor –

and each is important because in protecting habitats we are protecting species. It is not surprising that there are clear conservation benefits from marine reserves.

Next we looked at what happens outside a reserve, and whether there are any benefits to fisheries. Obviously the goal of conservation was to have a reserve large enough for young to be produced in the middle of the reserve, not outside it, thereby minimizing export. In contrast, for fishery benefits you want to maximize export.

When different species of fish are tagged inside a reserve we can monitor how far they swim outside the reserve. There is spillover from reserves as things get crowded in there, but these fish do not go far, usually to the general area around the reserve. Other changes which are likely outside a reserve are potentially much more important and more difficult to measure, such as the export of larvae. Individuals in the reserve get big and produce young. Zygotes or larvae are transported in ocean currents away from the reserve, over varying distances. This is much more difficult to document as they are not marked, but we can calculate the number of young produced by the number remaining in the reserve.

When fish are allowed to get big and fat, the reproductive benefit is immense, and is directly related to the size of the individual. Take the vermilion rockfish. One that is 37 centimetres long produces about 150,000 young, while a fish that is 60 centimetres long produces 1.7 million young. Allowing fish to get bigger in reserves therefore brings tremendous benefits. Since this study was undertaken, it has been found that in some fish, not only do the fat females produce more young, they produce higher-quality young which do well when less food is available.

A network of marine reserves is a series of reserves connected by the movement of larvae, juveniles and adults within a large marine ecosystem. Because species spend time in different habitats – a larval habitat, a juvenile habitat, an adult habitat – it is important to think comprehensively and holistically in this large ecosystem context. In addition, an important function of reserves is to provide insurance against mismanagement or unanticipated consequences. Much of our management of fisheries historically has been on the edge: when something unexpected happens, it triggers a crash.

Reserves also have an important role as scientific reference areas, shedding light on the results of fishing and other pressures outside the reserve, looking at both direct and indirect human impacts.

The conclusion of the study is that reserves can offer important benefits in protecting local areas. Individuals grow larger in protected habitats, there are immediate benefits outside the reserve and a likely larger fishery benefit, although that varies from one species to another and is a function of local conditions.

Until very recently the ocean was replete with *de facto* marine reserves – areas where it was too far, too deep or too rocky to fish. These have essentially disappeared now. Fishing can take place almost everywhere, and many are of the opinion that marine reserves offer a huge opportunity to recover some of what has been lost.

Much of the information from this working group on the science of marine reserves was summarized in a booklet, *The Science of Marine Reserves,* as well as a 15-minute video, so there is an active effort to communicate the results of this project to fishermen, citizens' groups and others interested.

Turning to governments, a few have taken the step of creating ocean policies that set out a distinctly different future. Canada and Australia have done this. We have had no policy changes in the United States but there have been two national commissions that have recommended sweeping changes. I had the pleasure of serving on the Pew Oceans Commission; it was independent and the first comprehensive review of ocean practice and policy in over 30 years. We were a collection of 18 individuals – elected officials, business leaders, fishermen and conservationists – and we spent three years going around the country talking to citizens. We also commissioned studies by scientists to inform our deliberations.

Looking at the United States as an economic zone, we realized that the area of oceans over which the United States has jurisdiction is about 1.5 times larger than the area of the US continent, a huge responsibility that we have not yet grasped. The conclusion of the Pew Oceans Commission was that this public domain should be managed as a public trust, and although we are a long way from that, we have made a series of far-ranging recommendations[1]. Essentially, if people want healthy fisheries,

1 America's Living Oceans: Charting a Course for Sea Change

vibrant coastal economies, abundant wildlife, clean beaches and healthy seafood, they have to have intact, functional ecological systems. Therefore one of the commission's strong recommendations was to make protecting and restoring the ecosystems that provide this bounty and these services a goal of all ocean policy and practices in the country.

This approach was taken up by the national US Commission on Ocean Policy (USCOP) appointed by Congress, which reported to the president[2]. Both this and the Pew commission are in line in terms of their conclusions, highlighting the importance of stewardship, regional governance, ecosystem-based management, working out how to link the land and sea, science and education. The power of these two commissions is going to be significant. There will be much activity in the next few years as we begin to share the results and publicize them more widely. The recommendations have significant policy implications. I have already mentioned the primary emphasis on protecting and restoring the ocean ecosystems and having clear institutional responsibility. There are currently over a dozen federal agencies dealing with oceans and more than 140 congressional laws that regulate them. The left hand does not know what the right hand is doing, and there is a huge gap in the middle. Institutional responsibility and governance changes are highlighted by both commissions – as are changing the regional Ecosystem Management Council's structure and investing in monitoring and research.

It is a new dialogue, and I think there is beginning to be increased awareness on the part of political leaders. But it is very early, and there is a huge amount yet to be done. It is encouraging that the debate is being informed by science, and that scientists are playing such an active role in it.

Much of the science is also informing citizen action. There is a wealth of activity on a global scale through a variety of non-governmental organizations, but also on a local scale. There is increased interest in the oceans, and in individuals using the power of their own choices to help make a difference. Choosing sustainably caught or farmed seafood is gaining currency, but it is still in the very elementary stages. There is considerable momentum for creating networks of marine reserves and marine protected areas, working for governance changes and individuals creating their own environmental preferences. There are a number of citizens' action groups in the United States focused on making choices at the market or restaurant in favour of sustainably caught or farmed seafood. In

2 An Ocean Blueprint for the 21st Century – USCOP

Europe the Marine Stewardship Council is a lot more active than it is in the United States; there are similarities and differences.

In summary, then, marine systems are exceedingly challenging, more so than most of what is happening on land, and that is challenging enough. The fact that most people do not come into contact with the oceans is a huge barrier to increasing public understanding and creating political will. However, a new awareness is emerging and is beginning to trigger some bold new actions. The state of California took the Pew Oceans Commission's report and actually passed a law – the Californian Ocean Protection Act – which does exactly for the state what we recommended for the United States as a whole. California also passed the Marine Life Protection Act, which mandates the creation of marine reserve networks. In Australia, under the Great Barrier Reef Marine Park Authority, about a third of the park is now marine reserves. Other countries are taking similar actions.

I think the time is right for meaningful change; it is not soon enough, but it is happening. The oceans are vast, historically very bountiful, and also dangerous and mysterious. These are the impressions people have. The oceans are home to billions of creatures and essential for all life because they provide critical ecosystem services. This is what is at risk, and human well-being is at risk because of the changes taking place in the oceans. The current choices we are making in terms of energy, agricultural practices, coastal development, horticulture and fisheries are all unsustainable and leading to an impoverished future, but this is not inevitable. It is not too late to change, although it will be exceedingly difficult. I believe there is both urgency and hope in making this transition. We can choose a different future informed by science that understands the consequences of trade-offs, science that leads to a better set of options for more individuals.

Dr Jane Lubchenco is Wayne and Gladys Valley Professor of Marine Biology,
and Distinguished Professor of Zoology, Oregon State University.