THE MONACO OCEAN ACIDIFICATION ACTION PLAN

Summarizing progress, setting out priorities

Heralding the next era of action on ocean acidi cation

OCEAN ACIDIFICATION presents a very real threat to all those depending on the sea and its resources around the world in the coming decades. My interest in this issue goes back many years. In 2008 I hosted the Second International Symposium on The Ocean

JUST OVER A DECADE AGO the world first recognized the problems that some coastal communities and economic sectors were starting to experience from progressive ocean acidification. The chemical process behind ocean acidification was described in the 1950s, but it wasn't until the 1980s that observations from the north-east Pacific Ocean showed that real changes were already happening. By the 1990s coral reef biologists began to explore this issue and the First Symposium on The Ocean in a High CO_2 World, held in 2004, provided the opportunity for the global science community to start exploring how ocean acidification might affect the ability of marine organisms to produce their shells and skeletons from calcium carbonate minerals. We now know that ocean acidification is adding to other significant global drivers of marine ecosystem change, such as ocean warming and deoxygenation.

Since 2004, much progress has been made in investigating, understanding, evaluating and communicating the challenges caused by ocean acidification. Those advances have not only transformed our understanding of the problem, and increased our concern of the severe and urgent threats now faced, but have also resulted in new organizational frameworks to support scientific research and international policy discussions.

CAROL TURLEY, PLYMOUTH MARINE LABORATORY, UK

This Action Plan was developed by the Ocean Acidification international Reference User Group (OAiRUG), with representatives from both the scientific and research users communities. The Plan aims to share progress and set priorities for developments in science and policy to keep pace with impacts we are starting to see in ecosystems and economic sectors most vulnerable to ocean acidification. This plan is as much for governments, policy advisers and decision makers, as it is for new stakeholders and the existing ocean acidification experts who form the current 'ocean acidification community'. Whilst this plan is not comprehensive, it highlights major achievements and is intended to take stock of scientific and political activities, whilst also fostering a broader debate on priorities for action in the coming decade.

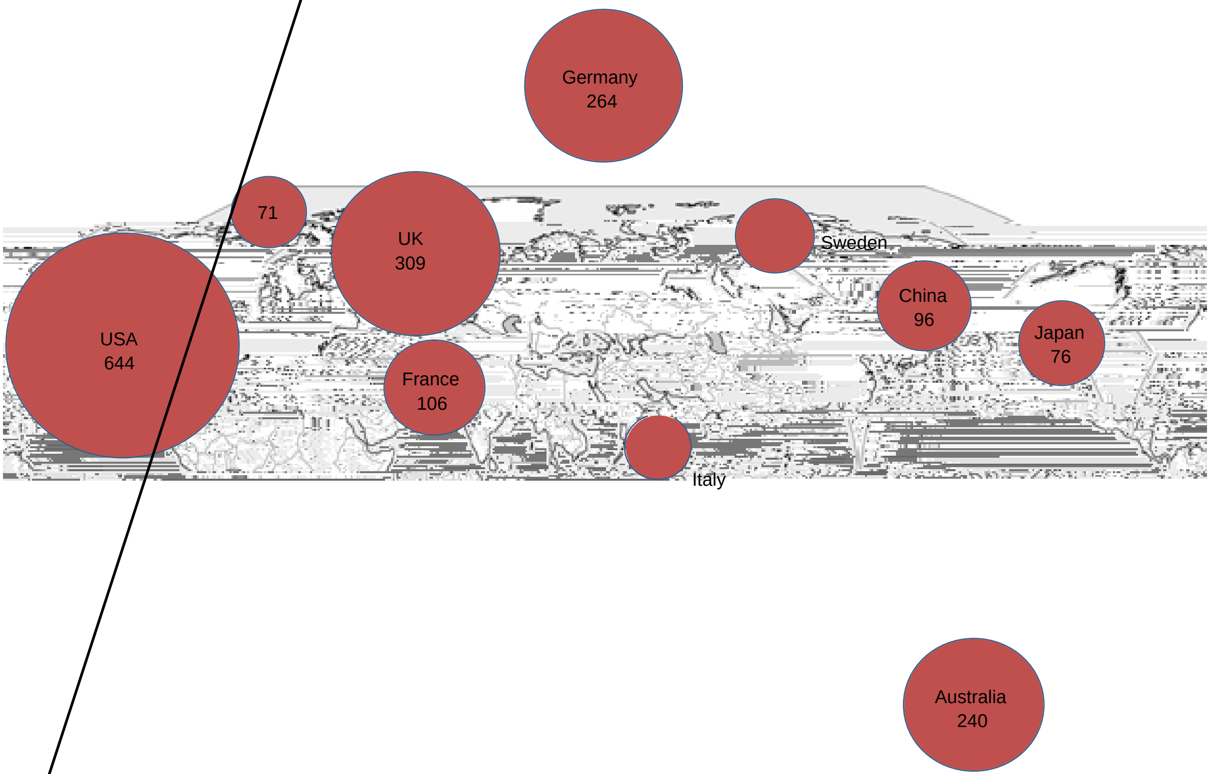
Ten Monaco Action Plan priorities to address ocean acidification

1. Shift the emphasis of scientific research from individual species to ecosystems, in order to understand impacts on food webs and to assist the parameterization of models.
2. Devise long-term experimental studies to understand adaptation as well as acclimation.
3. Consider multiple factors, underlying principles, and natural variability to gain better confidence of future impacts under 'real world' conditions.
4. Support efforts to reduce anthropogenic CO_2 emissions at sufficient scale and speed to avoid dangerous climate change and dangerous ocean acidification.

6. Match the development of ocean acidification observational networks to the needs of communities, industries, regions and governments in order to secure the scale of investment and support needed to develop forecasting capabilities.

8. Identify and develop relationships with new stakeholders that are likely to be affected by ocean acidification.

10. Invest in education and communication, aimed at a wide public audience, and scientific training to support capacity development in vulnerable regions that currently lack such capabilities.


Germany
264
71
UK
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Sweden
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Japan
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USA
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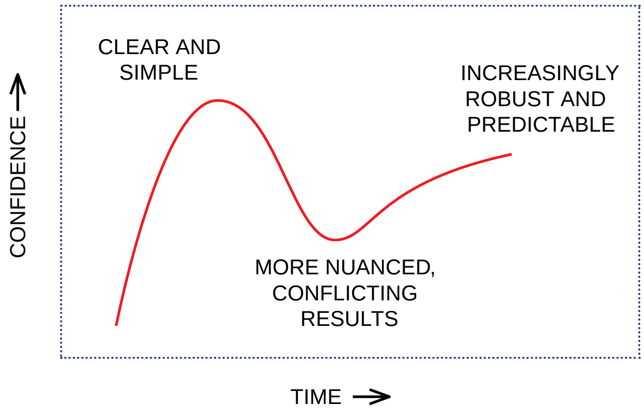
An era of nuance: a paradox and a challenge

After S. Doney



OA young eld of research

over time through acclimation and multi-generational adaptation. Thus there remains considerable uncertainty regarding the overall impact at the ecosystem scale. Combining the results from the very many laboratory experiments (meta-analyses) shows that signi cant negative effects include reduced survival, impaired calci cation, slowed growth and development, and decreased abundance. Positive effects (arising from enhanced photosynthesis) include increased growth rates in some eshy algae and diatoms. Such positive effects must be seen in the context of the far broader array of negative responses that will inevitably interact and result in a very changed ocean environment in the future – unless there are rapid and substantive reductions in CO_2 emissions.

Analyses of multiple data sets, expert surveys, and assessments have been used by the international scienti c community to determine the con dence level surrounding the science of ocean acidi cation. For example, the 2013 Summary for Policymakers published by the International Geosphere – Biosphere Programme (IGBP), the Scienti c Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO). That report reviewed the state of scienti c knowledge on ocean acidi cation, based on research presented at the Third International Symposium on The Ocean in a High CO_2 World, held in Monterey, California, in September 2012, the largest gathering of ocean acidi cation experts to date. Similar conclusions were reached in subsequent assessments of ocean acidi cation impacts by the Convention on Biological Diversity and the Intergovernmental Panel on Climate Change.

Research by the Mediterranean Sea Acidi cation in a Changing Climate project (MedSeA) has documented how ocean acidi cation impacts are being felt at a regional sea-scale. Their ten facts on ocean acidi cation and warming come from the combined ndings of more than 100 scientists from 22 institutions in 12 countries and include the information that the Mediterranean Sea has already warmed nearly 1°C over the last 25 years, with increases in acidity of around 10% over that period (http://medsea-project.eu/wp-content/uploads/2011/08/10_facts_english.pdf) ry of effects of acidi cation among selected taxonomic groups. Effects are either a mean percent e or decrease in a given response, or as no overall positive or negative response. After Kroekeret al. 2013.

ı levels of con dence on the science around ocean acidi cation
n Summary for Policy Makers IGBP, IOC, SCOR 2013.

DENCE	SCIENCE
HIGH	The capacity of the ocean to act as a carbon sink decreases as it acidi es
	Ocean acidi cation is caused by CO_2 emissions from human activity to the atmosphere that end up in the ocean
	The legacy of historical fossil fuel emissions on ocean acidi cation will be felt for centuries
	Anthropogenic ocean acidi cation is currently in progress and is measurable
	Reducing CO_2 emissions will slow the progress of ocean acidi cation
H	The ocean is acidifying more rapidly than it has in millions of years
	Multiple stressors compound the effects of ocean acidi cation
	Cold-water coral communities are at risk and may become unsustainable
	Some seagrasses and phytoplankton species may bene t from ocean acidi cation
	The combination of ocean acidi cation and temperature negatively affects many organisms
	Molluscs (such as mussels, oysters and pteropods) are one of the groups most sensitive to ocean acidi cation
	If CO_2 emissions continue on the current trajectory, coral reef erosion is likely to outpace reef building sometime this century
	The varied responses of species to ocean acidi cation and other stressors are likely to lead to changes in marine ecosystems, but the extent of the impact is dif cult to predict
UM	Anthropogenic ocean acidi cation will adversely affect many calcifying organisms
	Pteropod (marine snail) shells are already dissolving
	Ocean acidi cation may have some direct effects on sh physiology, behaviour and tness
	Nitrogen xation in some cyanobacteria may be stimulated by ocean acidi cation
	Declines in shell sheries will lead to economic losses, but the extent of the losses is uncertain
	Negative socio-economic impacts of coral reef degradation are expected but the size of the costs is uncertain
W	Impacts of ocean acidi cation on ecosystems may affect top predators and sheries
	Ocean acidi cation will alter biogeochemical cycles at a global scale

Lessons from the past

There have been periods in Earth's history where we have indications that the oceans have been acidi ed (a lower pH than today). For instance, at the end of the Permian, ca. 251 Myr ago or at the Paleocene-Eocene Thermal Maximum (PETM), 55 Myr ago. These acidi cation events were also triggered by a carbon perturbation but had a different origin (volcanism and methane clathrates, respectively) than today. Nevertheless, all are characterized by catastrophic extinctions and biodiversity loss.

In brief:

- Ocean acidi cation has occurred in Earth History.
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DIRECT OBSERVATIONS from the last 25 years and reconstructions (from coral composition) going back to the 1940s show a trend of increasing dissolved CO_2 in the upper ocean, whilst pH is falling. These trends closely match the observed changes in atmospheric CO

The OAiRUG – and the RUG process it embodies – has the longest and most successful track record for any mechanism designed to connect end-users and decision makers to experts involved with ocean acidi cation research.

support national and regional research efforts in 2008 in Europe, before being broadened to new national research agendas in the UK, Germany, and the Mediterranean thus helping to more rapidly engage a broader stakeholder community in the challenges and issues to be faced from ocean acidi cation.

At the same time international symposia and meetings provided added coordination capabilities for the research community – most notably through the Ocean Acidi cation Working Group of the Surface Ocean Lower Atmosphere Study (SOLAS) and Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) programmes and The Ocean in a High CO_2 World Symposia series.

Alongside these, wider efforts targeting international cooperation brought together natural and social scientists and economic experts to explore the societal impacts of ocean acidi cation and adaptation measures needed in order to detect how living ocean resources are harvested and used. The rst international workshop on the socio-economics of ocean acidi cation, organized by the Centre Scienti que de Monaco (CSM) and the Environment Laboratories of the International Atomic Energy Agency (IAEA) in 2010, with support from the Prince Albert II of Monaco Foundation and the Government of Monaco, provided a venue for natural scientists and economists to introduce their perspectives on the topic of ocean acidi cation and to link these two communities. In 2012 the second international workshop gave particular attention to policy-related impacts of ocean acidi cation on livelihoods, trade and marine-based food supply. The workshop focused on sheries and aquaculture, and regional aspects of species vulnerability and socio-economic adaptation. The workshop brought together 55 natural and economic scientists to provide policymakers with recommendations for regional priorities in sheries and aquaculture. A third international workshop took place in early 2015 with a focus on ocean acidi cation impacts on coastal communities.

By 2011 it became apparent that the research challenge had changed from one of encouraging national research on ocean acidi cation, to one on how to support the new national research agendas that have successfully emerged from these efforts. In particular there was an increasing need to support international collaboration, offering greater ef ciencies, capacity sharing, and reduced costs. Activities needed to set global standards for ocean acidi cation research are dif cult if not impossible to fund nationally.

A new international project to ful l this role was transposed into reality in 2013 in the shape of the Ocean Acidi cation International Coordination Centre (OA-ICC www.iaea.org/ocean-acidi cation), based at the Environment Laboratories of the International Atomic Energy Agency (IAEA) in Monaco. At the same time the existing, mostly European, reference user group for ocean acidi cation research was transitioned to a fully global initiative, with support from the Prince Albert II of Monaco Foundation. The Ocean Acidi cation international Reference User Group (OAiRUG http://www.iaea.org/ocean-acidi cation/page.php?page=2198) cooperates closely with the OA-ICC on communication activities. At a rst meeting of the OAiRUG in 2013 HSH Prince Albert II announced the creation of a Monegasque Association on ocean acidi cation (Association Monégasque sur l'Acidi cation des Océans; AMAO; http://www.fpa2.com/article.php?idarticle=30&lang=en) to provide long-term coordination in Monaco and to further promote international activities on ocean acidi cation alongside existing efforts such as the OAiRUG and the Monaco-based OA-ICC.

The Ocean Acidi cation international Reference User Group (OAiRUG)

The OAiRUG is an international forum for scientists and stakeholders on ocean acidi cation. It was formed in 2012 and rst met in the autumn of 2013. Funded by the Prince Albert II of Monaco Foundation, its role is to work alongside the Association Monégasque sur l'Acidi cation des Oceans (AMAO) and the Ocean Acidi cation International Coordination Centre (OA-ICC) to bring scientists, policy advisers, decision makers, and end users together to:

- examine in detail the types of data, analyses and products that are most useful to managers, policy advisers, decision makers and politicians in explaining ocean acidi cation;
- take a major role in the process of ocean acidi cation science to policy knowledge transfer; and
- achieve wider society engagement and understanding of the implications of ocean acidi cation, in conjunction with other global environmental stressors such as ocean warming and deoxygenation.

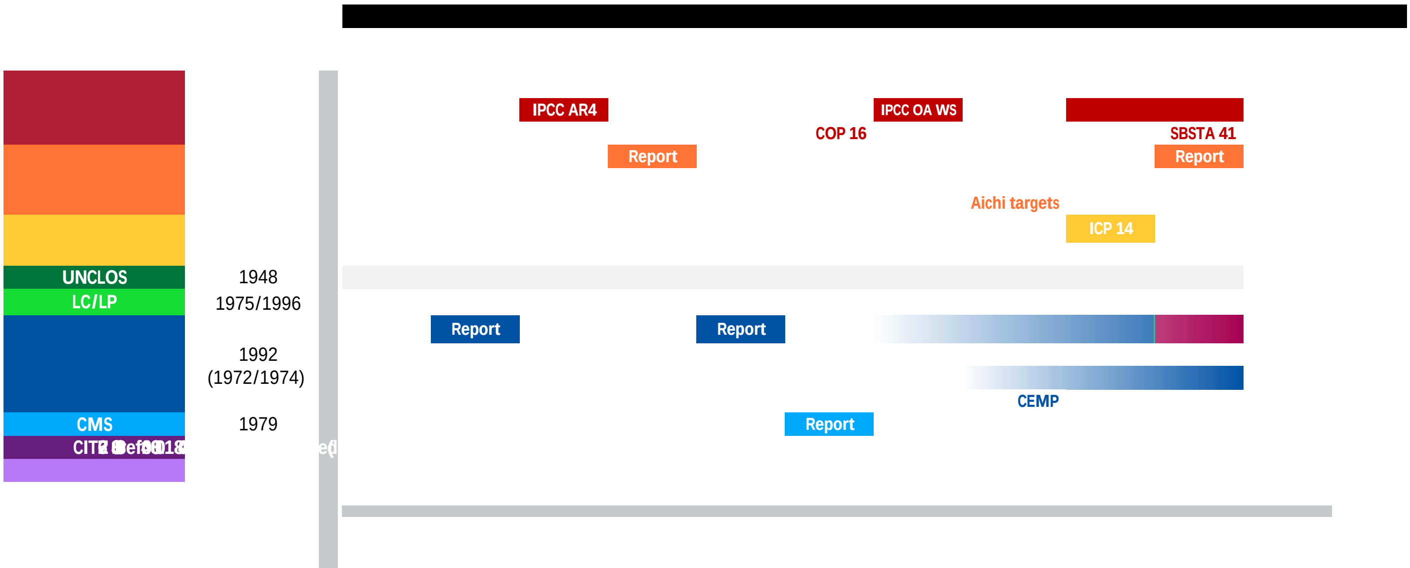
http://www.iaea.org/ocean-acidi cation/page.php?page=2198

http://www.fpa2.com/article.php?idarticle=19

Ocean Acidi cation International Coordination Centre

The OA-ICC was launched following recommendations by the SOLAS IMBER Ocean Acidi cation Working Group of IGBP and SCOR, and the EPOCA Ocean Acidi cation Reference User Group, and in response to the increasing concern of IAEA Member States. Isotopic and nuclear techniques are powerful tools to study the impact of ocean acidi cation on primary production, growth and calci cation rates and the Environment Laboratories of the IAEA in Monaco have been studying ocean acidi cation since 2008.

It is supported by the IAEA 'Peaceful Uses Initiative' (PUI) through direct and in-kind contributions from several IAEA Member States and via research projects on ocean acidi cation, including national and programmatic contributions from: Australia, France, Italy (ENEA),


IPCC AR4
IPCC OA WS
COP 16
SBSTA 41
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Report
Aichi targets
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Where next with policy action?

Whilst intergovernmental organizations consider ocean acidi cation as a threat to the marine environment, urgent, more tailored international legislative action is required to mitigate, adapt and manage risks.

An optimist would look at past processes to tackle climate change through the UNFCCC and note that ocean acidi cation is merely the next step in a process that has built both in capacity but also complexity over the last 20 years:

- 1992 UNFCCC and goal to stabilize greenhouse gas concentrations.
- 1998 Kyoto Protocol and the reduction of CO_2 emissions by 5%.
- 2010 Cancún Agreement to limit warming to below 2°C.

As global ocean acidi cation, like warming, is caused by increased CO_2 concentrations, it would be logical to expect and require that the UNFCCC address ocean acidi cation and not just the current preoccupation on limiting warming to below 2°C to respond to its goal as described in Article 2:

THE FUTURE WE WANT, ARTICLE 2, RIO+20, 2012

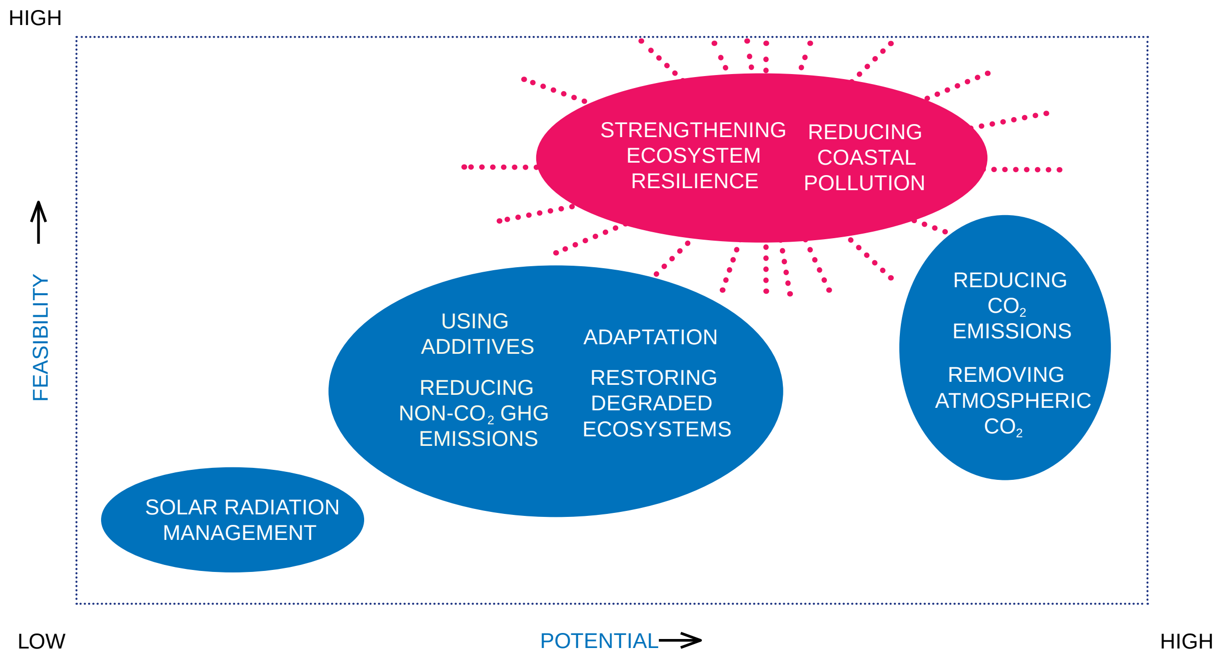
It becomes evident, however, that UNFCCC cannot be encapsulated by one single 'one-size- ts-all' climate target, or that if it does then the current emissions targets need signi cant tightening if they are to tackle the issue of ocean acidi cation.

So alongside climate policy, policy action also needs to be taken in a wide range of other fora, particularly the management of other stressors, such as coastal pollution, to build ecosystem resilience, to repair already deteriorated environments and to create appropriate adaptation mechanisms and increase ecosystem resilience. In essence there is a real discrepancy between appropriate and abundant legal frameworks that could address ocean acidi cation, and insuf cient or inef cient enforcement of existing policies to carry this out.

Looking to the future

Despite the last decade of focused activities the impacts especially higher up in food chains are still poorly understood, it is still a largely 'invisible' problem with impacts that are likely to be highly uneven geographically and politically. Ocean acidi cation emerged as an issue after most options to respond to climate change had already been identi ed and tested. New tests are needed and a variety of responses are available to buy time while keeping the pressure on signi cantly reducing CO_2 emissions. Since solutions to ocean acidi cation cannot be viewed in isolation, it will be necessary to address a range of other stressors including warming of the ocean, deoxygenation, eutrophication, air pollution (e.g. NOx and SOx), over shing, land-based sources of marine pollution, etc. The breadth of ocean and environmental treaties dealing with these issues need to account for the impact of ocean acidi cation and provide greater collaboration and knowledge exchange, at both international and national levels.

An attempt to compare the feasibility of different options to help address the onset of ocean acidi cation. After Billeet al. 2013.



REGIONAL GOVERNANCE ORGANIZATIONS

NEW AUDIENCES FOR OCEAN ACIDIFICATION INFORMATION

Whilst ocean acidi cation is recognized as a global issue, the impacts of an acidifying ocean are being, and will be felt, rst regionally and locally. Already the shell sh aquaculture industry of the NW USA has experienced its impact and many other regions may follow. Ensuring that regional governance organizations, especially in areas predicted to be at risk and vulnerable, are well informed is a critical activity for the coming years. Partnerships between regional government, academics and industry have shown to be particularly successful at delivering knowledge transfer in the north-west USA.

The goal is to encourage the adoption of ocean acidi cation as an issue for local management in vulnerable areas of the ocean. To do this information on ocean acidi cation should be positioned and packaged to explain how it will or may affect the local community. This represents a shift from presenting a chemistry answer, to one that explains how lives may be affected and what actions can be taken to solve the problem.

The ocean acidi cation research community therefore needs to translate the science into an accessible format, creating user advice fact sheets on possible local actions and their likely effectiveness as well as highlighting the implications for ecosystem services and cultural heritage. Moreover, stronger linkage and inter-operability between information and practices at local through to global scales is needed. Global information is needed to provide context for local conditions, conversely a composite of local coastal conditions is needed to inform the global ocean acidi cation conditions.

Tropical coral reefs have been estimated to provide globally around $US 30 billion in net bene ts each year. It is surprising then given the already signi cant risk that ocean acidi cation poses to the future health and stability of such reefs that the coral reef tourism industry does not seem to be strongly engaged (to date) in the debate on ocean acidi cation and the need to reduce carbon emissions.

The goal should be to encourage the coral reef tourism industry to become more aware of ocean acidi cation and its policy implications. To do this there is a need to support them to best understand reef resilience and through this to inform their investment decisions.

The ocean acidi cation research community should provide information to set this problem in the context of coral reef health, to explain the socio-economic consequences of inaction, and the risks for future health of reefs if signi cant decisions are delayed. A key part of this will be to nd within the industry key champions and people who can serve as ambassadors for change.

Whilst it is still not clear what impacts ocean acidi cation will have on sh stocks it is quite clear that the potential for impacts of some other sectors of the seafood industry – such as mariculture – could be very signi cant. The risk to sustainability of local communities is real and may become increasingly problematic in the coming decades.

To better understand the situation the research community should support the industry in getting ahead of the problem of ocean acidi cation before impacts occur. They could do this by documenting the effects on production and helping the most vulnerable sectors of industry located in the most vulnerable areas of ocean adapt to the realities of an acidifying ocean. This is with the hope that they can then become ambassadors for the issue just as members of the shell sh industry have already done.

To do this, information will need to be provided on how the industry can actively participate in observations, monitoring and forecasting of effects, by explaining how they can adapt and mitigate to minimize impacts and who they can align and cooperate with in this venture. An important part of this will be to develop and disseminate monitoring standards, and over time develop thresholds in commercial and food species.

Actions under Article 2 of the UNFCCC have to date focused on mean global temperature change as a key threshold for setting emissions targets. However, the inclusion of ocean acidi cation as an issue of concern requires that greater attention is directly given to atmospheric carbon dioxide, with the possibility that even deeper emission cuts might be needed to avoid dangerous marine ecosystem impacts. There is therefore an urgent need to bring climate negotiators up to date on the latest evidence on ocean acidi cation.

The aim is to provide a clear scienti c argument to help negotiators commit to tackling ocean acidi cation under the UNFCCC before the 2015 climate change conference in Paris (COP21). To do this the ocean acidi cation community needs to provide negotiators with the links and consequences between the likely commitments of Member States and the ocean acidi cation impacts that will result.

A rapid reaction from scientists to the contributions (INDCs – Intended Nationally Determined Contributions) that countries put forward in advance of COP21 to advise on those likely consequences would be very valuable.

Signi cant funding is required to address the economic implications of ocean acidi cation. One route to securing such support is by working more closely with development banks and aid agencies.

A key element of this is to connect and brief banks and aid agencies on the latest science and present predictions about vulnerable areas of the ocean and timescales by which impacts may be felt by local communities.

Greater clarity on the socio-economic consequences, and what can be done to alleviate these is urgently required.

The key end point for climate negotiations on ocean acidi cation is to signi cantly reduce the scale of anthropogenic carbon dioxide emissions which is driving further acidi cation of the ocean. It is therefore surprising that the industries that focus on emission reduction approaches to energy generation and provision have few visible links to the ocean acidi cation community. Such knowledge would support these industries in making stronger cases for why their technology should be adopted quicker than otherwise might be the case.

The key issue is therefore to bring the low carbon and ocean acidi cation communities together, to exchange information and to seek win-win situations. Not all low carbon industries have a small environmental footprint so a process of dialogue needs to take place to build a new set of ambassadors to help tackle ocean acidi cation.

A growing number of foundations and wealthy individuals are worried about environmental threats to the ocean. These funders take many different approaches, with some focused on speci c geographic areas and others more broadly. Few currently fund ocean acidi cation work, while most have some focus on more well-known impacts such as the effects of shing. Ocean acidi cation could overtake the ocean’s ability to support local dependent communities and may affect ecosystems and species.

The goal is to undertake targeted outreach and communication to raise the pro le of ocean acidi cation as a topic worthy of their investment. Information should be provided to help evaluate why they might prioritize ocean acidi cation and in such a way that they can gain insights into areas where funding is particularly needed within the subject area.

To ll this need the ocean acidi cation community should place their evidence in the context of the metrics that the foundations use – economics, human health and biodiversity – with a clear view provided on the provision of ecosystem services. One-to-one brie ng packages should be created to this effect.

Find out more

FAST-TRACK ACCESS to a selection of the latest literature and web links for key topics featured in the Monaco Ocean Acidi cation Action Plan.

Baird R, Simons M, Stephens T. (2009). Ocean Acidi cation: A Litmus Test for International LawCarbon & Climate Law Review 4:459.

Barnard N, Hain S. (2009). Impacts of ocean acidi cation on Marine Biodiversity. CBD Technical Series Report 46.

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