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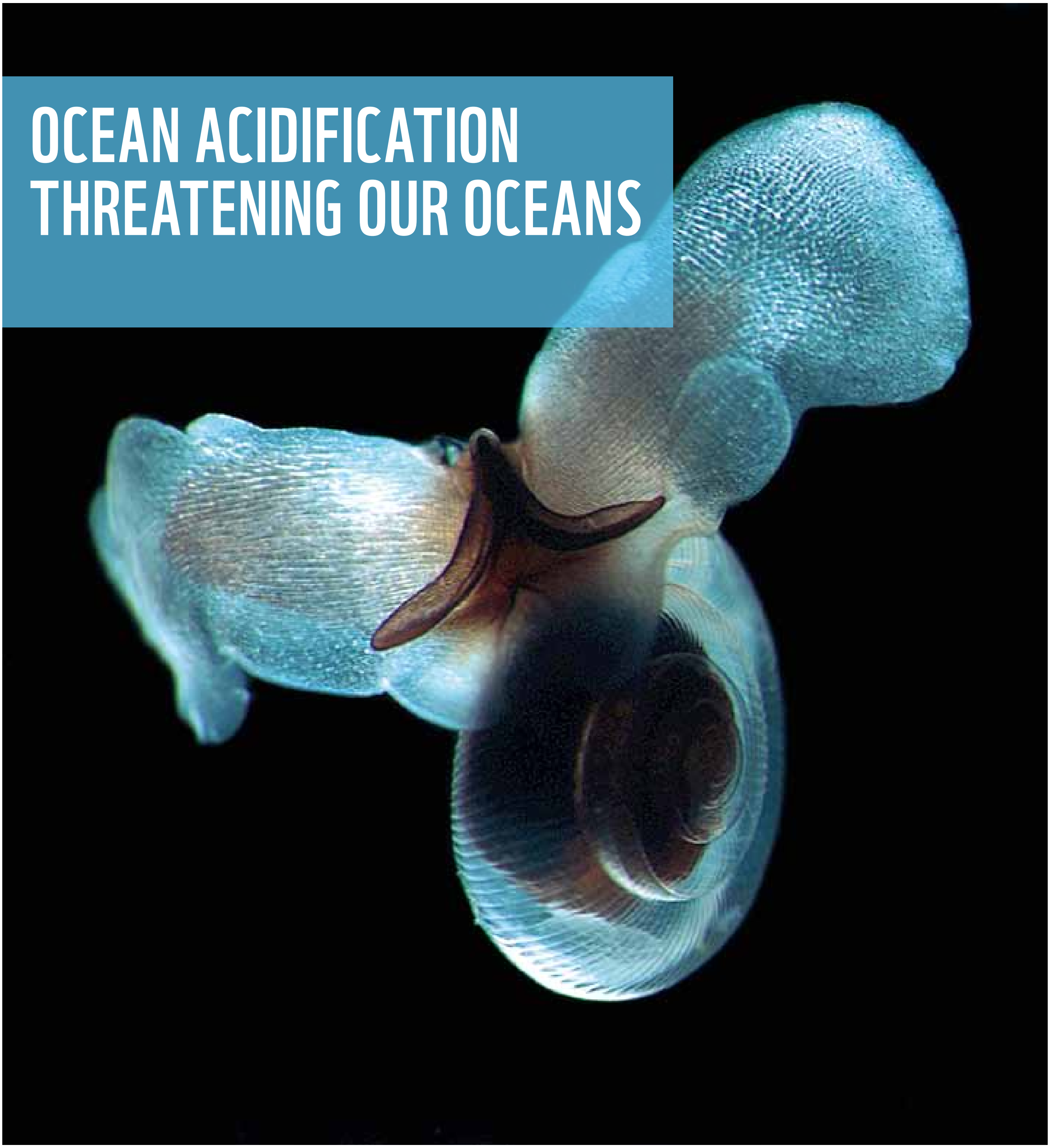

OCEAN ACIDIFICATION THREATENING OUR OCEANS

PUBLISHED BY THE WWF GLOBAL ARCTIC PROGRAMME

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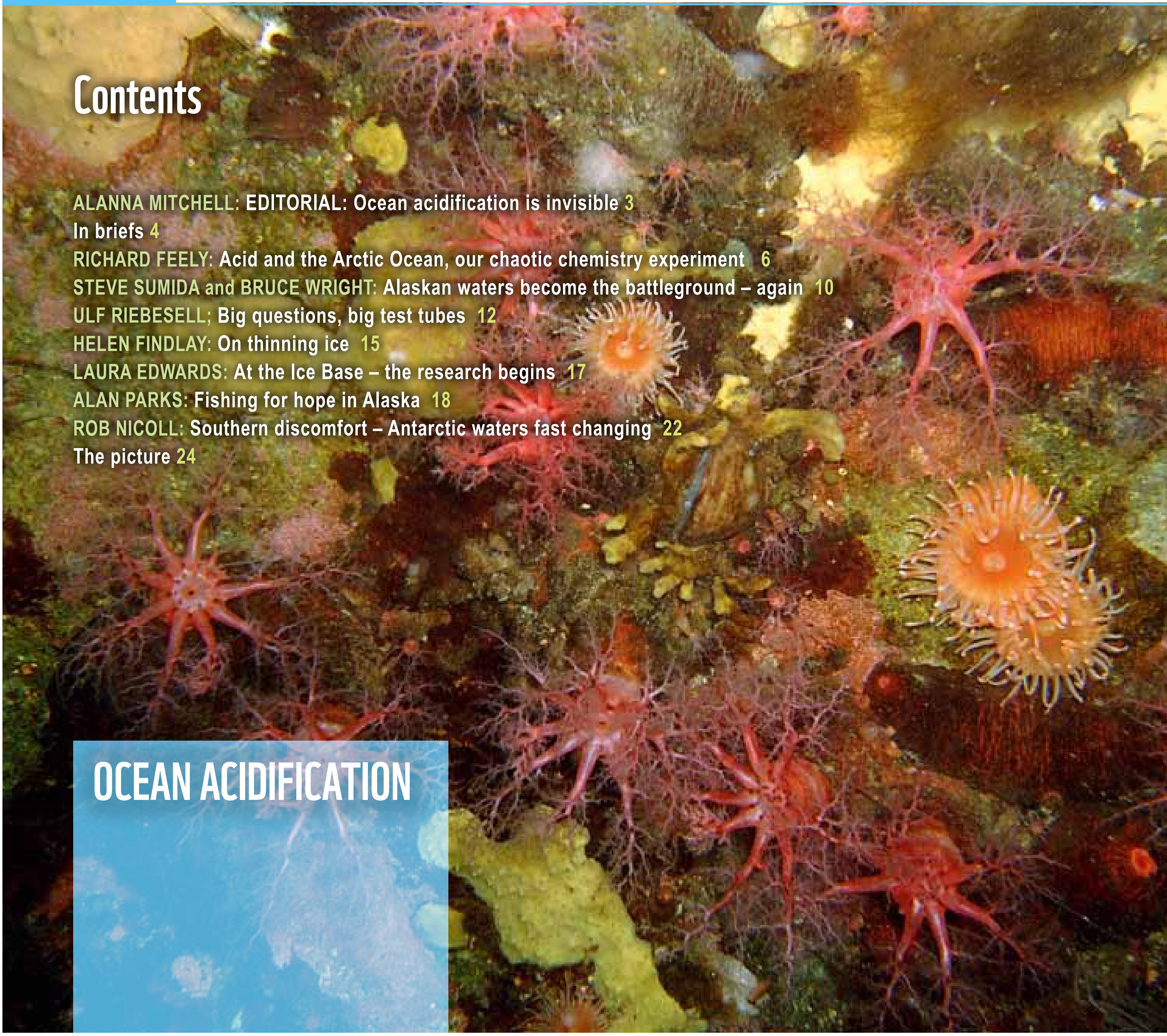

OCEAN ACIDIFICATION

Photo: British Antarctic Survey (BAS)."

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COVER:
Arctic pteropods commonly known as sea butterflies.

"*Pteropods are a particularly important food source for juvenile fish such as salmon and pollock.*"
Dr. Richard Feely, page 9.

Photo from:Dr. Russell R. Hopcroft Professor, Institute of Marine Science, University of Alaska Fairbanks

Ocean acidification is invisible

TO THE EYE, first of all. Just looking at it, you can't tell that the water's fundamental chemical composition – the dance of its hydrogen ions – has changed.

It's invisible on the political front, too. Off the radar. Excluded from international carbon discussions, including the most recent round in Mexico.

That's despite the fact that scientists are now worried that the growing acidity of the ocean is at least as big a threat to life on the planet as global climate change.

How? When we burn fossilized plants and animals – we call them fuels – we are putting the carbon from an ancient age into the atmosphere. So far, we've increased the concentration of carbon dioxide in the atmosphere from less than 0.03 per cent to nearly 0.04 per cent. That's higher than it's been in millions of years.

In the atmosphere, that carbon dioxide acts like a blanket, keeping heat near the planet's surface, inert and powerful enough to shift climate.

But about a third of that ancient carbon has been absorbed by the ocean's surface, molecule by molecule, in an inexorable exchange between the air and sea. In the ocean, carbon dioxide is not inert. It reacts chemically with water to produce carbonic acid.

Now, a couple of centuries into the fossil-fuel-burning industrial revolution, we've put so much ancient carbon into the atmosphere that the ocean has become about 30 per cent more acidic than before we began.

That's more acidic than the ocean has been for about 55 million years.

The implications? They cascade through the oceanic chemical soup that is the basic medium of life on the planet. More acidity means less available calcium. That means creatures that need calcium to make shells, bones and bony structures are having trouble.

Scientists are finding that corals are scrambling to make their reefs, oyster shells are thinner, some plankton are using more energy making shells than doing other functions critical to the basic workings of the ocean.

Along with that, the vulnerable larvae of oysters, snails and lobsters are struggling to mature. Fish become stupid, swimming toward predators instead of away because of an acid-made shift in their ability to smell. And these are just a few of the effects scientists have taken a look at.

The colder the water, the more quickly it absorbs carbon dioxide gas, and so the more acidic. That means the Arctic and Southern Oceans are becoming acidic about twice as fast as the average. A recent study calculated that the northern ocean will be the first in the world to hit the point of no return with dangerous, systemic acidification. By the end of this decade, 10 per cent of the Arctic will be so acidic it will damage, rather than foster, life.

Unless we do something. The key is to sharply reduce carbon emissions into the atmosphere and the ocean. Halting ocean acidification has to be a priority at every round of global climate change discussions. And we need to make ocean acidification visible. ○

ALANNA MITCHELL is a journalist and author whose latest book, *Sea-sick: The global ocean in crisis*, has become an international bestseller. It won the Grantham Prize for excellence in environmental reporting. www.alannamitchell.com

■ **READERS OF THE CIRCLE** are accustomed to editorials that frame the issue we're examining in each edition, along with information about WWF solutions and initiatives. We pride ourselves on being a solutions-oriented organization. However, ocean acidification is too new and the research too incomplete for us to fully understand how to tackle this growing threat to our oceans. We are working with organizations such as the Catlin Arctic Survey, which you can read about in this edition that spent weeks on the sea ice to conduct research into the effects of ocean acidification. Another article features the team of Dr. Ulf Riebesell, which lugged two tonnes of equipment to Svalbard, then posted 24-hour watches over their experiments aimed at analyzing the impact of acidification on plankton communities. This sort of cutting edge research will help inform further actions, although it already seems clear that there will be changes to the ecology of the Arctic Ocean, and that the root cause of these changes is the amount of carbon dioxide that people are pumping into the atmosphere. This is our first concerted effort to tackle ocean acidification at a circumpolar level, and to bring together some of the experts urging and taking action. As Alanna Mitchell writes, "we need to make ocean acidification visible." The WWF Global Arctic Programme believes that by increasing its visibility here through The Circle, that we are contributing to a solution.

Clive Tesar, editor-in-chief

WWF at Japan conference

DIRECTOR OF the WWF Global Arctic Programme, Alexander Shestakov, hosted a side event at the 10th meeting of the Conference of the Parties to the Convention on Biological Diversity (COP-10) in Nagoya, Japan in October. "When Parks are not Enough," delivered a strong warning about ecosystem resilience and change in the Arctic.

"Warming in the Arctic is proceeding at twice the global rate," Shestakov says. "This challenges the resilience of arctic ecosystems and calls for a major re-think of arctic conservation."

RACER moves forward

A SLATE OF EXPERTS met in Ottawa to help WWF's Global Arctic Programme fine-tune a project designed to identify, map and raise awareness about circumarctic regions that are resilient to change. RACER – Rapid Assessment of Circumarctic Ecosystem Resilience – "is designed to quickly provide guidance on conservation options in the Arctic in the face of rapid change," says Martin Sommerkorn, WWF's senior climate change advisor. "RACER will identify those areas that are underpinning future viability of Arctic ecosystems, including people." Sommerkorn says he was particularly encouraged by the support for RACER expressed by scientists, technical consultants and other experts who attended the week of workshops in Ottawa, Canada. "There is solid recognition that an assessment embracing the changes to come is critically needed and that assessing resilience is the right way to move forward," he said. RACER is designed to provide guidance to government, industry and other stakeholders to ensure functional arctic ecosystems.

Arctic fox

WWF-SWEDEN is involved in a new program aimed at boosting and protecting the arctic fox population in Scandinavia.

"The Felles Fjellrev program is attempting to repopulate areas where no arctic foxes are currently breeding," says WWF spokesman Tom Arnbom. "If successful, then the two, smaller isolated areas for this species will broaden and grow into one large habitat between Norway and Sweden that would allow fox populations to breed with each other, strengthening the gene pool."

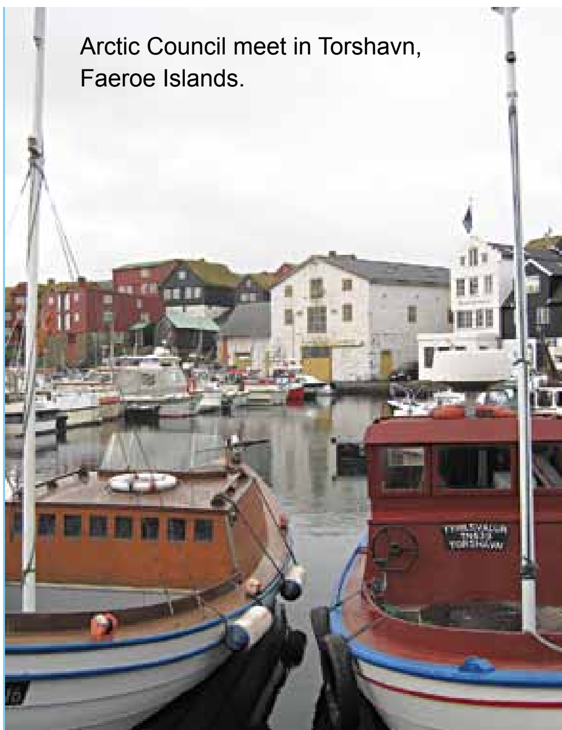
Arnbom says the number of arctic foxes in Sweden is a fraction of what it was 150 years ago – just 130 foxes according to numbers from summer, 2010 – due to increased hunting in the 19th and 20th century. But he says a recent shortage of small rodents – the fox's main source of food – is also a factor.

"The Scandinavian lemming has been particularly scarce," Arnbom says. "To help the arctic fox in Scandinavia, supplementary feeding with dog pellets and removal of predatory red foxes close to arctic fox dens has made a difference in survival rates."

Arctic fox populations suffered severe declines in 2008-2009 when only a few pups out of each litter survived. But the summer of 2010 saw the best survival rate in 35 years. In total, 24 pairs raised pups, largely due to a combination of active management and relatively high rodent population. By late autumn, numerous lemming tracks were observed in arctic fox territory. "If this trend continues, there could be an incredible increase of lemmings by next summer, which would result in a boom in the arctic fox population throughout Scandinavia," Arnbom says.

Economic forum champions WWF management plan for Barents Sea

WWF-RUSSIA'S initiative for a Complex Management Plan for the Barents Sea was highlighted at the Second Arctic Economic Forum in Murmansk in October. The



Arctic Council meet in Torshavn, Faeroe Islands.

Photo: Clive Tesar

Council flies search & rescue pilot

GLOBAL ARCTIC PROGRAMME communications director Clive Tesar represented WWF at the October Arctic Council meeting in Torshavn, Faeroe Islands. The meeting heard a progress report on a search and rescue agreement being negotiated between the arctic states. "While search and rescue is not our core business, the fact that it is intended to be a legally binding agreement negotiated under the auspices of the Arctic Council is momentous," says Tesar. "If successful, this would be the first agreement of its kind leading to a significant strengthening of the council as a multilateral instrument."

Bear necessities

IN OCTOBER Arctic NI polar bear specialist Geoff York gave a presentation on WWF's efforts in bear/human conflict reduction at the Southern Hudson Bay Polar Bear Recovery Plan Workshop in northern Ontario, Canada. "Ontario is home to the southern-most population of polar bears in the world and climate change is considered the greatest threat to the survival of these bears," York says. "In Hudson Bay and James Bay, climate change is causing sea ice to thaw earlier and freeze up later. It's believed this reduces the amount of time polar bears can spend on the ice feeding on seals to put on fat to support their seasonal fast." Over the last 30 years, the break-up of sea ice has occurred about 9.5 days earlier per decade in northern James Bay and between five and eight days earlier per decade along the southern Hudson Bay coast of Ontario.

Where the bears are:

YORK ALSO scored some ice time with the bears on the shores of Hudson Bay in November along with some of the world's leading polar bear and climate researchers. York and other experts were able to do live broadcasts to audiences around the world via the Polar Bears International "Tundra Buggy 1" mobile studio. "While we were with the bears waiting for the sea ice to form, world leaders were gathering to meet in Cancun, Mexico, to discuss progress on a global climate deal. It was extremely gratifying to be able to speak with concerned citizens around the globe about the decline of this iconic species." York also completed a fall coastal survey of the entire coast of the province with Manitoba Conservation and Polar Bears International. This was the first such survey of its kind conducted at this time of year. "This will be a useful baseline," says York. "In future years we can look at this survey of the distribution of bears and their numbers along the coast to get a better idea of how they're reacting to the longer ice-free periods."

chairman of the Murmansk regional Duma (legislature), Evgeny Nikora, said there is "growing conflict in the numerous approaches in monitoring sea activity and degradation of sea ecosystems in areas of intense economic development."

WWF Russia wants to see principles such as an ecosystem approach to management, adaptive management and preservation of species fixed in international law and national legislation as in other leading sea countries.

Norway backing down on CO_2 reduction promises

WWF IS pressuring the Norwegian government to reject an application by The Store Norske Kullkompani (SNSK) to extend coal mining operations on the arctic archipelago of Svalbard.

"Extended coal mining on Svalbard directly contradicts Norway's ambitious Co2 reduction goals and its promised climate change commitments," says WWF-Norway's head of climate change and energy, Arild Skedsmo. "Even considering this application flies in the face of what the Norwegian government has promised to do to reduce greenhouse gas emissions."

The coal is largely used for energy production. Its main markets are Germany and the Netherlands.

SNSK's application to extend coal mining on the archipelago is currently undergoing environmental impact assessments. If approved, the construction of infrastructure for the new mine could begin as early as this summer.

"The government of Norway is guilty of speaking rhetoric on climate change," says Skedsmo. "If Norway isn't prepared to make even miniscule concessions on economic activities such as coal mining, how can we expect anyone else to?"

Acid and the Arctic Ocean, our chaotic chemistry experiment

Spanning an area of slightly over 14 million square kilometres, the Arctic Ocean is one of the most pristine and productive regions on earth, supporting surprising numbers of birds, fish, and marine mammals. Concern over the rapid loss of ice cover over the past several decades from the substantial climate change occurring in the region has led many scientists to speculate about the future health and well-being of its marine ecosystems. Oceanographer Dr. RICHARD FEELY explains how the Arctic Ocean now faces another threat – the same carbon dioxide surplus that is largely responsible for climate change is also altering the basic chemistry of the ocean.

Pacific walrus males at "haul-out" Round Island, Alaska,

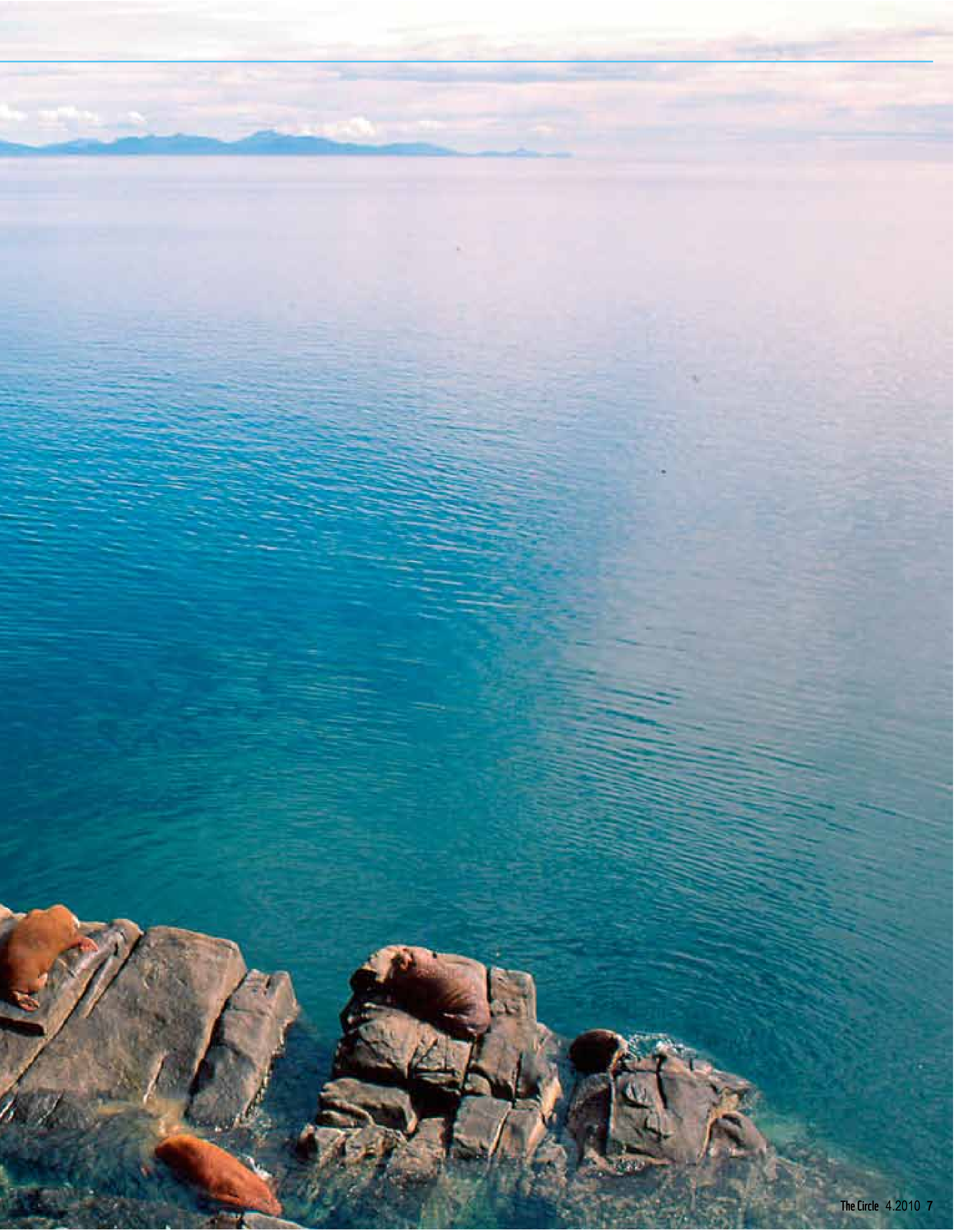


Photo: Kevin Schafer / WWF-Canon

OVER THE PAST 200 years the release of carbon dioxide (CO_2) from our collective industrial and agricultural activities has resulted in atmospheric CO_2 concentrations that have increased significantly. The atmospheric concentration of CO_2 is now higher than experienced on Earth for at least the last 800,000 years, and is expected to continue to rise. When carbon dioxide is absorbed by the oceans it reacts with seawater to form carbonic acid. The oceans have absorbed approximately 525 billion tons of carbon dioxide from the atmosphere, or about one quarter of the human-introduced carbon dioxide emissions released over the last two and a half centuries. This natural process of absorption has benefited humankind by significantly reducing the greenhouse gas levels in the atmosphere and minimizing some of the impacts of global warming.

DR. RICHARD A. FEELY is a Senior Scientist at the NOAA Pacific Marine Environmental Laboratory in Seattle and is a professor at the University of Washington School of Oceanography. His major research areas are carbon cycling in the oceans and ocean acidification processes. He co-chairs the U.S. CLIVAR/CO_2 Repeat Hydrography Program and is a member of the Steering Committee for the U.S. Carbon and Biochemistry Program. He was awarded the Department of Commerce Gold Award in 2006 for research on ocean acidification.

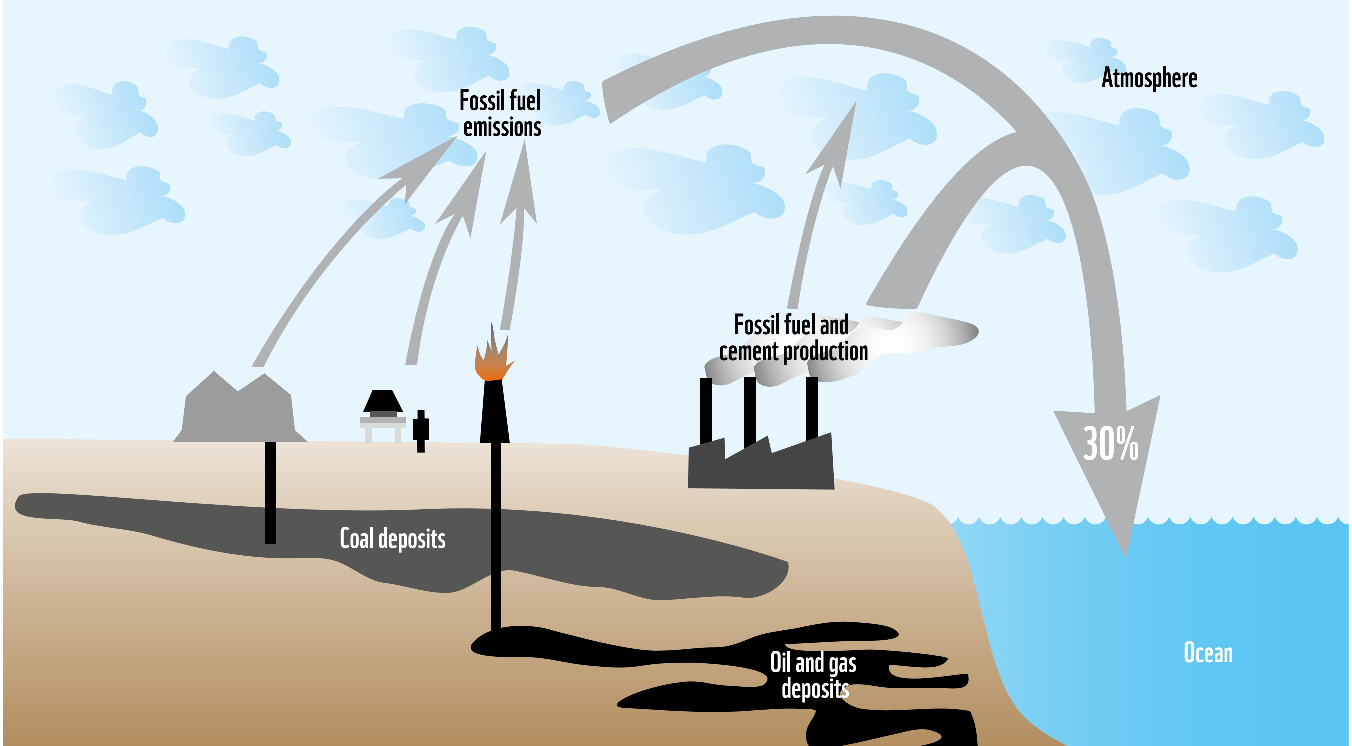
"...OCEAN ACIDIFICATION COULD AFFECT SOME OF THE MOST FUNDAMENTAL BIOLOGICAL AND CHEMICAL PROCESSES OF THE SEA IN COMING DECADES."

However, the ocean's uptake of 22 million tons of carbon dioxide per day is starting to have an impact on the chemistry of seawater. The pH of our ocean surface waters has already fallen by about 0.1 units from an average of about 8.2 to 8.1 since the beginning of the industrial revolution (on the pH scale, 7.0 is neutral, with points higher on the scale being "basic" and points lower being "acidic"). Estimates of future atmospheric and oceanic carbon dioxide concentrations indicate that by the end of this century the surface ocean pH decrease would result in a pH that is lower than it has been for more than 20 million years.

When CO_2 reacts with seawater, fundamental chemical changes occur that cause a reduction in seawater pH. The

Weisweiler power in North-Rhine Westphalia.

Photo: Andrew Kerr/WWF-Canon



The oceans are acidifying fast

Every day, more than 20 million tons of carbon dioxide are released into the atmosphere from the burning of fossil fuels. Nearly one-third of this pollution is absorbed by our oceans.

Over the past several decades, we have pumped so much carbon dioxide into the oceans that their chemical composition is changing. They are acidifying. And they are doing so at an alarming rate.

The increasing acidification of our oceans is already beginning to alter ecosystems and the very food web that sustains Alaska's fisheries. Higher acidity levels hamper the shell-building processes of species such as crabs, clams and corals.

Graphic: Alaska Marine Conservation Council and WWF-Alaska

interaction between CO_2 and seawater depletes the availability of carbonate ion, critical to shell formation for marine animals such as corals, plankton, and shellfish. This phenomenon, commonly called "ocean acidification," could affect some of the most fundamental biological and chemical processes of the sea in coming decades. The Arctic Ocean's cold waters tend to absorb carbon dioxide more rapidly than is absorbed by the warmer seawater to the south, making it more vulnerable to acidification. Over the last three decades, retreat of summertime sea ice cover has exposed shelf waters to the atmosphere and has allowed additional absorption of carbon dioxide. The combination of these processes accelerates the rate at which pH decreases in the region.

EFFECTS ON FISH AND SHELLFISH

Research is showing that ocean acidification may have negative effects on commercially important fish and shellfish larvae. Exposure of fish to lower pH levels can cause decreased respiration rates, changes in blood chemistry and changes in enzymatic activity. The calcification rates of the edible mussel and Pacific oyster decline with increasing CO_2 levels. Squid are especially sensitive to ocean acidification because it directly affects their blood oxygen transport and respiration. Sea urchins raised in lower-pH waters show evidence for inhibited growth due to their inability to maintain internal acid-base balance. Scientists have also seen a reduced ability of marine algae and free-floating plants and animals to produce protective carbonate shells. These organisms are important food sources for other marine species. One type of free-swimming mollusk called a pteropod is eaten by animals ranging from tiny krill to whales. Pteropods are a particularly important food source for juvenile fish such as salmon and pollock.

"…WE CAN EXPECT TO SEE SIGNIFICANT IMPACTS THAT ARE OF IMMENSE IMPORTANCE TO MANKIND"

Ocean acidification research is still in its infancy, so it is impossible to predict exactly how the individual species responses will cascade throughout the marine food chain and impact the overall structure of marine ecosystems. It is clear, however, from the existing data and from the geologic record that some plankton and fish species will be reduced in a high-CO_2 ocean.

Ocean acidification may be one of the most significant and far-reaching consequences of the buildup of human-induced carbon dioxide in the atmosphere. Results from laboratory, field and modeling studies, as well as evidence from the geological record, clearly indicate that marine ecosystems are highly susceptible to the increases in oceanic CO_2 and the corresponding decreases in pH. Clams, oysters and other calcifying organisms will experience increasing difficulty producing their shells. Other species of fish and shellfish will also be negatively affected in their physiological responses due to a decrease in pH levels of their cellular fluids. Because of the very clear potential for ocean-wide impacts of ocean acidification at all levels of the marine ecosystem, from the tiniest phytoplankton to zooplankton to fish and shellfish, we can expect to see significant impacts that are of immense importance to mankind.

Ocean acidification is an emerging scientific issue and much research is needed before all of the ecosystem responses are well understood. However, to the limit that the scientific community understands this issue right now, the potential for environmental, economic and societal risk is quite high. It demands serious and immediate attention. Over the next century, if CO_2 emissions are allowed to increase as predicted, mankind may be responsible for increasing oceanic CO_2 and making the oceans more corrosive to calcifying organisms than at any time since the last major extinction, over 65 million years ago. Thus, the decisions we make about our use of fossil-fuels for energy over the next several decades will probably have a profound influence on the makeup of future marine ecosystems for centuries or even millennia. ○

Alaskan waters become the battleground – again

While general fossil fuel emissions are the greatest contributor to ocean acidification, new research suggests there are other factors that can locally exacerbate acidification, and introduce other chemical threats. As climate change reduces arctic ice, Aleut and Pribilof people will find themselves living at the crossroads of two shipping lanes – the Great Circle route to Asia and the fabled Northwest Passage. STEVE SUMIDA and BRUCE WRIGHT say people like them who live in the Bering Sea region will be increasingly exposed to unprecedented levels of virtually unregulated emissions from high-sulphur shipping fuels.

ALASKAN WATERS are once again the battleground for resolving hydrocarbon pollution. In 1989 the Exxon Valdez spilled crude oil that spread for hundreds of miles in the pristine waters along Alaska's coast. Our understanding at the time discounted oil as little more than a semi-noxious pollutant and a killer of birds. But oil toxicity research funded by the multi-million dollar settlement from the Exxon Valdez Oil Spill Trustee Council changed that almost benevolent view of oil pollution. We now know it is thousands of times more toxic than realized. Marine species have continued to be affected long after that catastrophic spill, evidenced mostly by salmon not returning to spawning streams. Many other birds and mammals were also harmed or killed.

> "...SHIPPING ACTIVITY AND LACK OF EMISSION CONTROLS OVER SULPHUR WILL CONTRIBUTE TO THE SERIOUS PROBLEM OF OCEAN ACIDIFICATION."

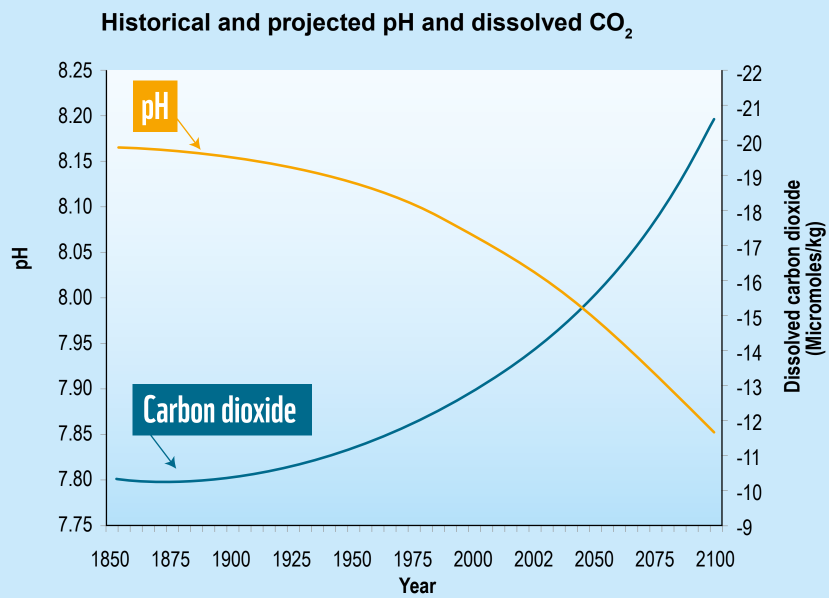
The pollution caused by burning high-sulphur fuels can have the same toxic effects. Ships in this region are allowed to use high-sulphur fuels with 45,000 parts per million sulphur – a much higher level than those set in most US waters of 10,000 ppm sulphur content for the majority of bulk fuel blends.

ALEUTIANS, PRIBILOF ISLANDS, WESTERN ALASKA REMAIN UNPROTECTED

Large container ships, tankers, bulk carriers, cruise ships and Lakers are significant contributors to air pollution in many of our nation's cities and ports.

Studies by the US Environmental Protection Agency (EPA) show that emissions from large marine vessels

The culprit: carbon dioxide released from burning fossil fuels



As the ocean concentration of carbon dioxide increases, so does acidity (causing pH to decline).

Source: Feely, Richard A., et al. (2006) Carbon Dioxide and Our Ocean Legacy

Ocean acidification is happening now, at a rate and to a level not experienced by marine organisms for more than 20 million years.

Ocean acidity has increased 30% since the Industrial Revolution and the rate of change has increased over the last 20 years. The burning of fossil fuels releases carbon dioxide, which gets absorbed by the oceans and changes their chemical composition, making them more acidic.

Graphic: Alaska Marine Conservation Council and WWF-Alaska

burning bunker fuel within 200 miles of the U.S. west coast shore can result in serious impacts to human and environmental health as well as permanent environmental degradation as far inland as the Grand Canyon, a distance of roughly 800 kilometres. As a result, the United States negotiated an international law preventing emissions from this fuel anywhere within 200 miles of the U.S. coast – except for the regions from the Alaska Peninsula, through the Aleutians and Pribilof Islands, western Alaska and along the Arctic coast. These regions remain exposed and unprotected to bunker fuel burning up to 45,000 parts per million sulphur content and unprecedented levels of virtually unregulated emissions. This at a time when the EPA requires all fuel for small marine vessels, highway, and non-road diesel engines including locomotives to be limited to 15 ppm sulphur content.

The EPA does not have any emissions monitoring stations in the Aleutian region. But the number of vessels moving through Unimak Pass is large and increasing, so we can't begin to know the exposure level for people living and working in the Bering Sea region.

We do know increased shipping activity and lack of emission controls over sulphur will contribute to the serious problem of ocean acidification and nutrient enrichment in the North Pacific Ocean through significant increases of nitrogen and sulphur deposits.

By 2020, international shipping is expected to account for 10 to more than 25 per cent of total annual sulphur deposition along the entire Atlantic, Gulf of Mexico, and Pacific coastal areas of the U.S. The impact of these deposits will extend inland for hundreds of kilometres. This means International shipping will contribute to total annual sulphur deposition not only along all U.S. coastal areas, but throughout the entire U.S. land mass, impacting sensitive terrestrial and aquatic ecosystems in the vast interior and heartland regions.

Researchers with a U.S. Forest Service study conducted in Southeast Alaska found evidence of sulphur emissions affecting lichen communities. The authors concluded that the main source of sulphur and nitrogen found in lichens is likely the burning of fossil fuels by cruise ships. Lichen are an important food source for caribou and there is a probability that large vessel emissions are damaging lichens and affecting the southern Alaska Peninsula caribou herd which is an important food source for local subsistence-based cultures. This herd has been decreasing in size, has poor calf survival and low pregnancy rates resulting in a ban on caribou hunting in this region. One can only imagine the effects these emissions are having on the dwindling Bering Sea fishing stocks. ○

STEVE SUMIDA is the Program Manager/Grant Director, Tanadgusix Corporation, an Alaska Native village corporation created under the Alaska Native Claims Settlement Act.

BRUCE WRIGHT is an ecologist and senior scientist with the Aleutian Pribilof Island Association. He led the effort to study energy issues in the Aleut region including the development of a marine transportation plan.

Big questions, big test tubes

Huge “test tubes” inside eight and a half metre-high floating frames, are used to investigate the effects of ocean acidification on the marine ecosystem in Kongsfjord, Svalbard, Norway.

By the end of this century, the projected changes caused by ocean acidification will go beyond anything organisms have experienced in the last 20 million years of their evolutionary history. Arctic waters are home to a wide range of creatures that build shells, both free-swimming and on the ocean floor, including shell fish, sea urchins, coralline algae, and calcareous plankton. Many of these species provide crucial links in the arctic food web, such as the sea butterflies (pteropods), which serve as food for fishes, seabirds and whales. Dr. ULF RIEBESELL reports on research studying the impacts of ocean acidification on plankton communities.

FROM MAY TO JULY 2010, a group of 35 researchers of the EU-funded European Project on Ocean Acidification (EPOCA) conducted the first major CO_2 perturbation experiment in the Arctic Ocean. Led by the Leibniz Institute of Marine Sciences (IFM-GEOMAR) nine mesocosms – giant, 17 metre “test tubes” – were placed in the Kongsfjord off the north-western coast of Svalbard, an archipelago in the Arctic constituting the northernmost part of Norway.

Each mesocosm was filled with about 50 cubic metres of seawater. The enclosed plankton community was then exposed to a range of different CO_2 levels as projected to develop between now and the middle of the next century and was closely monitored over a period of six weeks. The EPOCA scientists, who stayed at the Ny Ålesund research

35 scientists took part in the research in Kongsfjord.

ULF RIEBESELL has studied the impacts of ocean acidification on marine organisms and ecosystems for the past 15 years. He is on the executive board of the European Project on Ocean Acidification (EPOCA) and coordinates the German national programme on ocean acidification (BIOACID). He is a professor at the Leibniz Institute of Marine Sciences (IFM-GEOMAR) in Kiel, Germany.

station, sampled the mesocosms daily with plankton nets, water samplers and pumps, and conducted measurements.

EPOCA's 2010 mesocosm campaign involved molecular and cell biologists, marine ecologists and bio-geochemists as well as ocean and atmospheric chemists. The team set out to address a range of urgent questions concerning the impacts of ocean acidification on arctic ecosystems. How will ocean acidification affect the production of food at the base of the arctic food web and its transfer to consumers at higher levels? How will ocean acidification influence competition and trophic interactions at various levels of the pelagic ecosystem? Will there be winners and losers of ocean acidification?

Another set of questions concerns the possible consequences for the cycling of key elements. Will ocean acidification affect the store of carbon in the Arctic Ocean? Will it change the turn-over and balance between the primary building blocks of life such as carbon, nitrogen and phosphorus? A third set of questions concerns the exchange of climate-relevant gases between ocean and atmosphere. Will ocean acidification affect the production of these gases and if so, will it amplify or dampen global climate change?

The scientists participating in this unique campaign, the first of its kind in polar waters, had to face a range of technical and logistical challenges. In addition to the nine mesocosms, each weighing nearly 2 tonnes, the team had to transport more than 150 boxes of scientific equipment to the high Arctic. IFM-GEOMAR, as the coordinating institute, received support from the Greenpeace vessel Esperanza, which transported the mesocosms and other heavy equipment from Kiel to Ny Ålesund and back as part of its 2010 Arctic Campaign. Another challenge was the risk of damage to the mesocosms by drifting sea ice and icebergs calving off the three glaciers extending into the Kongsfjord. This could only be avoided by posting 24-hour ice watches and pushing icebergs off-track with small boats to keep them from colliding with the moored mesocosms. Considering the many unknowns involved in this endeavour, the experiment went surprisingly well and according to plan. The scientists collected nearly 15000 samples and acquired data for over 45 parameters characterizing the responses of the arctic ecosystem to ocean acidification. The results of this study will be presented at various international conferences in early 2011 and are expected to provide the first comprehensive insight into the sensitivities of the arctic ecosystem to a rapidly acidifying ocean. ○

On thinning ice

The summer sea-ice melt season of 2010 saw the third lowest ice extent in the satellite record and continues the trend of a declining summer sea-ice extent seen over the last three decades. Both the Northwest Passage (above Canada and Alaska) and Northern Sea Route (above Russia) were both open in September. The disappearance of the ice has implications for acidification in the Arctic Ocean. Scientist HELEN FINDLAY recently accompanied the Catlin Arctic Survey to Nunavut to conduct ocean acidification research. It was the first expedition to take water samples from the sea ice in winter. Previous Arctic measurements have been taken from ships in open water during the summer. Here she comments on the current status of ocean acidification research.

Research shows polar waters are less able to buffer effects of acidity.

NEWLY-OPEN OCEAN waters and reduction in sea-ice are examples of how the Earth's climate systems are changing. These changes have serious consequences for the uptake of carbon dioxide into the ocean and the subsequent change in ocean chemistry which results in oceans becoming more acidic.

Colder waters have a higher capacity to hold more dissolved gases, such as CO_2. That means the Arctic Ocean, for example, can absorb more CO_2 from the atmosphere than tropical oceans. The Arctic Ocean also has naturally lower levels of important ions, such as carbonate ions, making it less able to buffer changes in acidity. So the Arctic Ocean is particularly vulnerable to ocean acidification. Model projections suggest the Arctic could become corrosive to calcium carbonate minerals (aragonite and calcite) in the next 20 to 50 years. The small amount of carbon data that has been collected from the Arctic Ocean shows that aragonite undersaturation is already occurring seasonally in some areas. However, there are complex and poorly understood interactions between the sea ice and the flow of CO_2 between the atmosphere and the ocean. Additionally, the organisms that live in and under the sea

HELEN FINDLAY was an ice base scientist on the Catlin Arctic Survey in 2010. She has a PhD in biological oceanography and is currently the Lord Kingsland Research Fellow at Plymouth Marine Laboratory, UK. She also took part in the European Project on Ocean Acidification. Her current research projects include the impact of ocean acidification and global warming on marine organisms and ecosystem function.

ice play an important role in transporting carbon between the atmosphere and the ocean. These organisms could themselves be at risk from the impacts of ocean acidification.

For many years it was thought that sea ice acts as a barrier or "lid" to the ocean, essentially preventing any flow of CO_2, so that when the sea ice melts and exposes seawater to the atmosphere there is a flow of CO_2 into the ocean. This would suggest that as areas of the Arctic Ocean become free of ice in summer there could be an increased uptake of CO_2 into the ocean which will further exacerbate ocean acidification.

However, recent studies suggest that the interaction is not quite so straightforward. As sea-ice forms, the salts in the water are extruded out into small channels (brine channels) that flow through the ice. These brine waters have highly concentrated levels of CO_2 and buffering compounds (alkalinity), which can flow into the surface ocean and could change the dynamics of how CO_2 transfers between the ocean and the atmosphere. To further complicate the system, plants and animals that live in and under the sea-ice contribute to transporting carbon by photosynthesis and respiration, as well as forming calcium carbonate shells and skeletons.

CONSEQUENCES COULD BE SEVERE

There is growing concern that marine organisms could be stressed by ocean acidification. Many oceanic organisms use carbonate minerals to make shells and skeletons, but these structures will dissolve as the seawater becomes more acidic. Perhaps more importantly, nearly all physiological processes are sensitive to changes in pH. Each organism only has a certain amount of energy to make structures, develop and reproduce. This energy balance could be affected by changes in pH. If calcifying organisms have to produce more calcium carbonate structures to replace the structure that is dissolving, this could affect their energy balance.

While scientists know the chemistry of the Arctic Ocean is changing, there is much more uncertainty about how those chemical changes will disrupt the functioning of these marine organisms. The consequences could be severe, not only for the individual species, but also for large-scale processes, such as carbon cycling, the food web and even how our climate is regulated.

Two recent projects, the European Project on Ocean Acidification (EPOCA) and the Catlin Arctic Survey (CAS2010) are attempting to address some of the key questions about how carbon cycles between the atmosphere and the ocean through the sea ice.

"THERE IS GROWING CONCERN THAT MARINE ORGANISMS COULD BE STRESSED BY OCEAN ACIDIFICATION."

The primary aim of the CAS 2010 was to gather a baseline dataset that will inform scientists how carbon naturally cycles through the sea-ice during the important transition from the cold, dark winter period to the warmer, light spring period. This information will help to confirm the current status of the Arctic Ocean in terms of its current pH level and its ability to cope with increases in CO_2. The data will also inform scientists about the role of sea-ice in CO_2 uptake into the ocean and how biological processes contribute to ocean acidification or its amelioration. Other experiments assessed how important zooplanktons – such as copepods and pteropods – are affected by changes in pH.

EPOCA carried out larger- and longer-term experiments on the impact of ocean acidification on both benthic (bottom-dwelling) and pelagic (water column) organisms.

The studies were carried out on large organisms such as sea urchins, cockles and pteropods but also on small organisms, phytoplankton and zooplankton. These all play key roles in the functioning of the marine ecosystem either as part of the food web, in structuring the habitat or in cycling of nutrients. Any disruption to the food web will have implications further along the chain. Pteropods, commonly known as sea butterflies, are free-swimming snails with a calcified shell. They are important prey for many larger Arctic predators, such as Arctic Cod. Experiments to date have shown that these delicate creatures could be at risk from ocean acidification. Clams and cockles are also important shellfish in the Arctic and are the main food source for walruses and many Arctic sea birds. Although there have only been a few studies on Arctic shellfish, studies from more temperate regions suggest that ocean acidification could cause changes in the energetic balance of these organisms. If they have to allocate more energy to growth and calcifying their shell, that means less energy is available for reproduction. Even subtle changes in an organism's physiology can have severe impacts on the population structure which in turn will affect the ecosystem community and the flow of energy through the food web.

INDUSTRY ALREADY LOOKING NORTH

With the Arctic potentially ice-free in summer in just a few decades, industry and commercial organisations are already looking north. The oil and gas industries will seek to exploit new reserves, fisheries industries will look to exploit new fish stocks and shipping industries will look to exploit shorter shipping routes. These additional stresses on this environment will add to the difficulties faced by organisms living in a warming, acidifying ocean. It is therefore imperative that there is continued research into what role the Arctic plays in absorbing carbon dioxide from the atmosphere, how ocean acidification might develop in the Arctic Ocean and how this in turn will affect the key organisms that live there. ○

At the Ice Base – the research begins

Researcher LAURA EDWARDS was co-funded by WWF and the Royal Geographic Society to take part in the Catlin Arctic Survey. This is one of her blog postings from their base camp at Ellef Rignes Island, in Nunavut, Canada

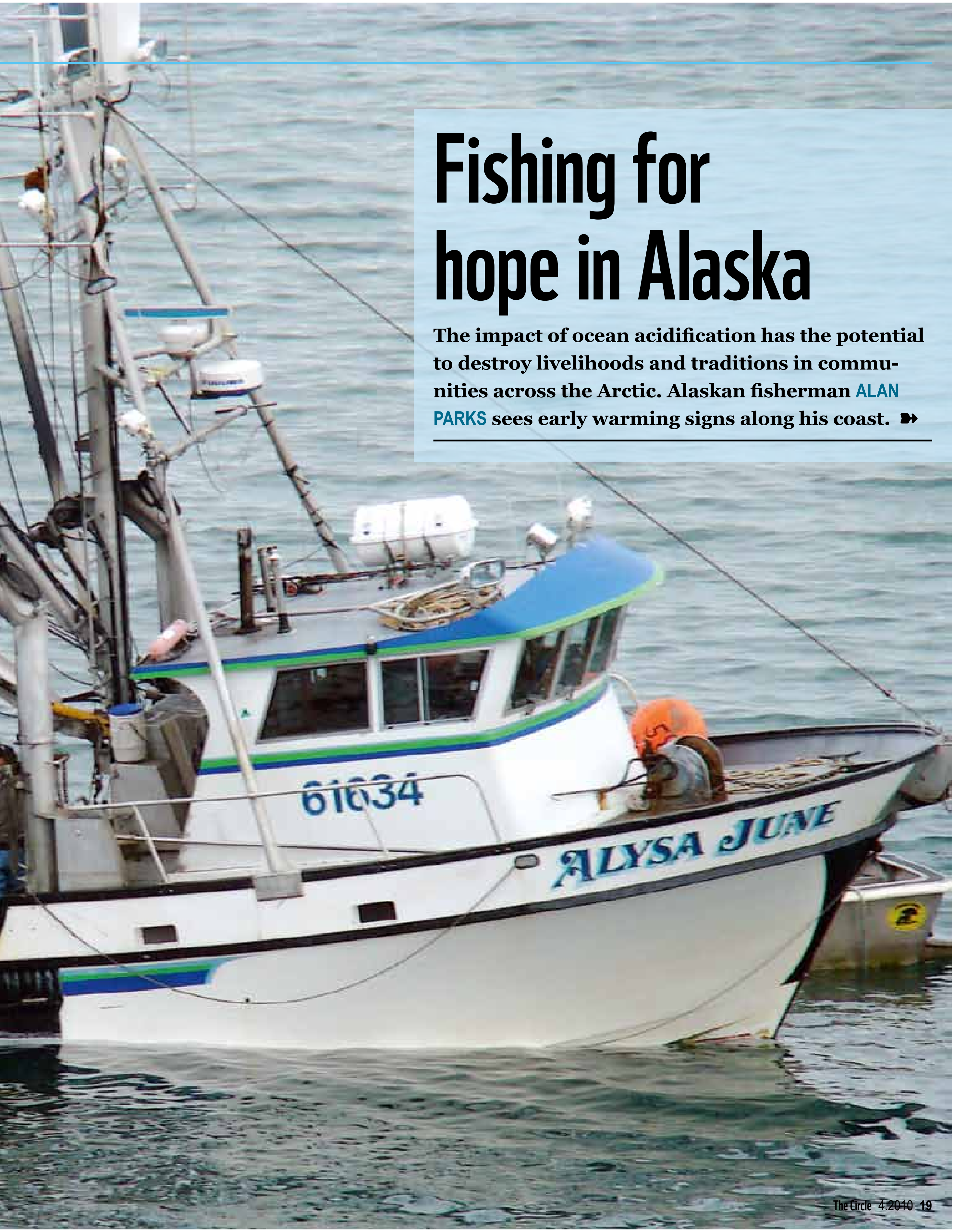
BASED ON FIRST YEAR sea ice approximately 1.5 m thick and about 10 km from the rugged coastline of Isachsen on Ellef Rignes Island the location of the Catlin Arctic Survey 2010 Ice Base site is stunning. It's quite surreal here, like being on a different planet and it's not as flat as you might think. The ice we're camped on is flat but to the north and south of camp there are regions of multi year ice which have ridged up over time and created a bizarre but beautiful rubbled ice landscape.

Our sample site is approximately 2 km west of camp and initially we used a skidoo to get all the equipment out there to take the samples of water chemistry, biology and underlying physical measurements (currents and temperature profiles). As well as the water studies, we are also taking ice core samples for analysis and atmospheric studies to help with the determination of CO2 flux through the sea ice. The skidoo like many mechanical and digital systems did not like the extreme cold and broke down and it chose to do so on the day a storm developed whilst we were at the sample site. We ended up having to return to camp during the storm on foot. The temperature at the ice base had been around -25 to -40 °C for our first week in camp but the night of the storm, with winds gusting up to 60 mph, temperatures that night reached below -60 °C with wind chill.

Our husky cross, Brownie, came to the rescue for future trips to the sample site. As we no longer had the skidoo, man and dog worked together to haul the science equipment to the sample site. Brownie really enjoyed herself and pulled hard and now gets upset if we don't take her with us on sampling days. We've had some very successful sampling days so far and the Catlin Arctic Survey 2010 project still has nearly a month to run so hopefully we should collect a really good set of data for the period. Ceri has been delighted to find a wide variety of plankton in the waters (copepods, pteropods) and the electronic equipment seems to all be working well. Our initial ice base team have now headed back home and been replaced with Paul Ramsden (Ice base manager), Alastair Humphreys (Communications manager), John Huston (Polar guide), Malin Hoiseth (Ice base chef) and Russell (Inuit guide). They're all settling in well and getting use to camp life. We made some good friends within the original ice base staff and miss them but I'm sure they'll be some new good friendships that develop with the new group. ○

Laura Edwards is a researcher at Bangor University studying the flux of carbon dioxide through sea ice and gaps in the sea ice, known as polynyas. Her research background is in oceanography, glaciology and remote sensing.

The Alysa June bringing in a net full of salmon caught in Aniakchak Bay, Alaska.



Fishing for hope in Alaska

The impact of ocean acidification has the potential to destroy livelihoods and traditions in communities across the Arctic. Alaskan fisherman ALAN PARKS sees early warming signs along his coast. ➻

Photo: Buzz Hoffman/Creative Commons

A STEADY RAIN falling from a cloudy June sky limited my vision as I steered out of the Naknek River and into the steel-gray waters of Bristol Bay. Alaska's 2010 salmon season was underway and prospects were good for a profitable harvest. But lurking just beneath the surface of that optimism, there is a shadow of uncertainty.

The seemingly pristine waters off Alaska conceal a troublesome secret. Like oceans everywhere, they're growing acidic, a condition that directly threatens my livelihood, that of my friends and neighbors, indeed our very way of life. What's more unsettling is the fact this impending calamity is man-made.

DISRUPTION OF FOOD CHAIN

Ocean acidification results from human activities that release millions of tons of carbon dioxide into the atmosphere each day. A third of it ends up in the world's oceans increasing their acidity. Normally mildly alkaline, scientists warn that without dramatic reductions in carbon emissions, ocean acidity could increase 150 per cent by century's end.

If conditions become acidic enough, the shells on corals, mollusks and crustaceans will dissolve. Sea life conditioned to the current alkalinity probably won't have time to adapt to rapid increases in acidic conditions.

Why is that important to fishermen? The food chain supporting salmon and other species in Alaska waters could be disrupted. Here's an example of how: vulnerable species include planktonic mollusks known as pteropods, an important part of the food chain feeding certain species of salmon. Scientists tell us that a decrease of just 10 percent in pteropod production can lead to a 20 per cent drop in mature salmon body weight.

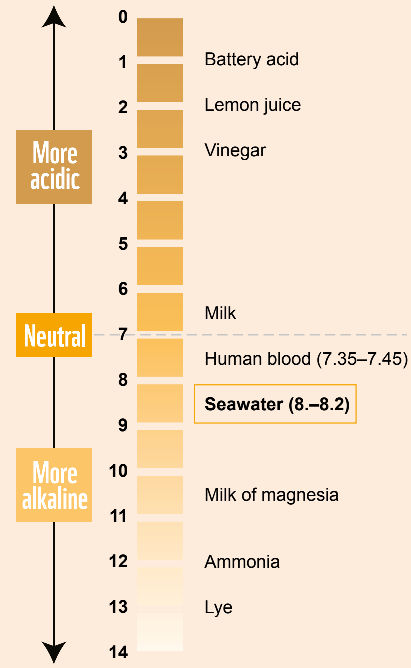
If current trends continue, pteropod populations could collapse, with grave consequences for the salmon food chain. Similar impacts could affect other elements of the food chain, and thus other commercial species. The effects on Alaska's economy would be profound.

Alan Parks has been commercial fishing in Alaska waters for over 30 years. He is a strong advocate for sustainable management that promotes community-based fisheries and working waterfronts. He lives in Homer, Alaska with his two children Ella & Hoxie.

The north is particularly vulnerable

Cold water can hold more gas than warmer water. As a result, ocean waters around Alaska and throughout the Arctic are absorbing more CO_2 – and therefore acidifying – faster than the global average. The shallow waters of Alaska's continental shelf compound the problem because there is less mixing of seawater from deeper ocean waters.

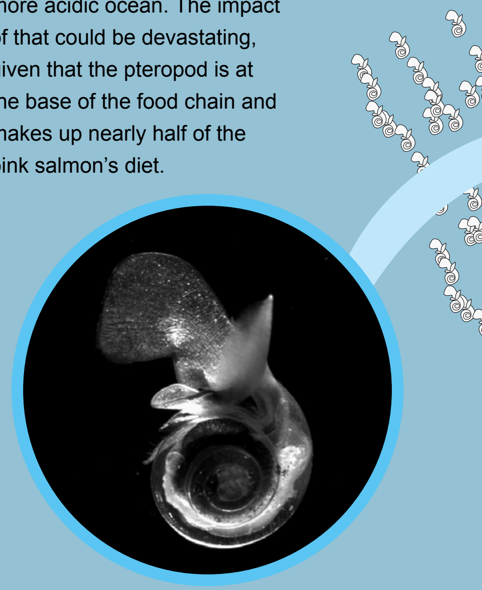
The pH scale



"IF FISHERIES DECLINE, SO WILL THE ECONOMIES OF MANY IF NOT ALL OF ALASKA'S COASTAL COMMUNITIES."

Small changes, big consequences

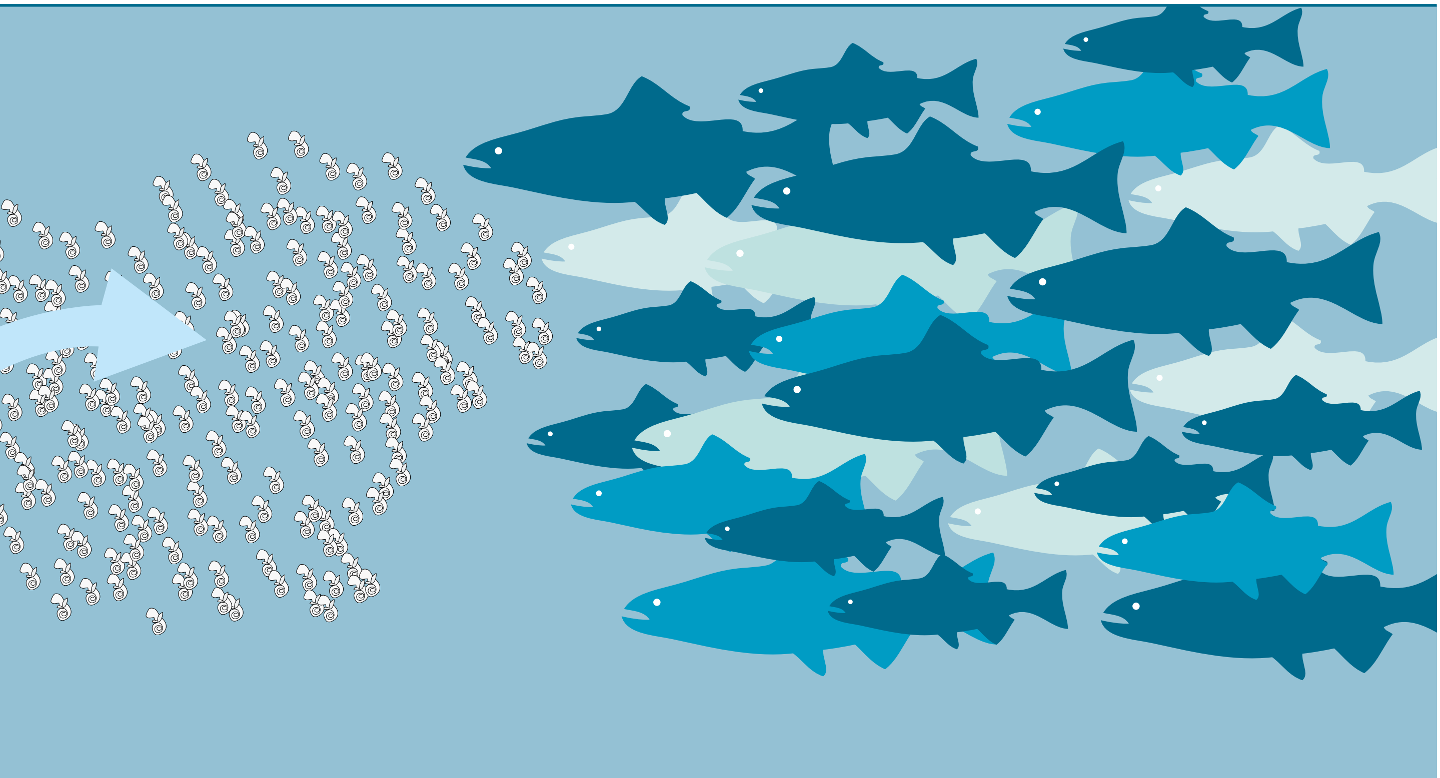
The shells of the tiny pteropod, also known as the sea butterfly or swimming sea snail, may be dissolved by a more acidic ocean. The impact of that could be devastating, given that the pteropod is at the base of the food chain and makes up nearly half of the pink salmon's diet.



JOBS, COMMUNITIES, TRADITIONS AT RISK

More than half the seafood harvested in the United States comes from Alaska, making it the third most important economic engine in the state behind North Slope oil and gas and federal spending. Preliminary figures show the 2010 Alaska salmon harvest will take in over 164 million fish. State data indicates some 90,000 jobs are directly or indirectly sustained by Alaska's robust fishing industry. Those jobs are all at risk should ocean acidification continue unchecked.

If fisheries decline, so will the economies of many if not all of Alaska's coastal communities. Imagine whole villages and cities left without their primary sources of income. Residents would



Graphic: Alaska Marine Conservation Council and WWF-Alaska

"WHILE RESEARCH TAKES MONEY, POLICY TAKES WILL. IS THERE ENOUGH OF EITHER?"

likely be forced to move. Harbours would be largely empty of fishing boats. Traditions that have lasted thousands of years could disappear.

These devastating impacts on families, lifestyles and cultures would not be confined to Alaska. Arctic regions as a whole are particularly vulnerable to ocean acidification.

There is sufficient evidence proving ocean acidification threatens our futures and cannot rationally be ignored. Concerted, sustained and well-financed research is imperative if we are to learn how to reverse the trend toward acidity. Some of that research is underway at the newly established Ocean Acidification Research Centre at the University of Alaska Fairbanks.

But research alone cannot make change. Data needs to be translated into effective government policy targeting the sources of carbon dioxide that cause ocean acidification while promoting the development of nonpolluting energy resources. While research takes money, policy takes will. Is there enough of either? Recently, there have been some promising signs in the United States.

The 2009 Federal Ocean Acidification Research and Monitoring Act established ocean acidification programs within the National Oceanographic and Atmospheric Administration, the National Science Foundation and the National Aeronautics and Space Administration. The National Science Foundation recently awarded research grants funding studies around the nation, including the research at UAF. Similar programs are proceeding overseas.

Until that research is turned into effective law, however, ocean acidification

"MEMBERS OF THE FISHING INDUSTRY … SHOULD BECOME ROLE MODELS WHO PRACTICE ENERGY EFFICIENCY."

will continue to threaten our oceans and fisheries, especially here in the Arctic.

Of course, we don't have to wait for government action to change the way we conduct our daily lives. Members of the fishing industry, who are dependent on fossil fuels, should become role models who practice energy efficiency and conservation at all times.

For me, salmon fishing proved lucrative this summer. The poundage was down, but the price was up. I just can't help but wonder how much longer ocean conditions will permit me to be optimistic and successful. ○

Acidification of the ocean raises concerns for the health of deep sea corals and other bottom-dwelling invertebrates.

Southern discomfort – Antarctic waters changing fast

Photo: British Antarctic Survey (BAS).

Initial evidence indicates acidification in the Southern Ocean with be felt sooner and more acutely than in more temperate regions if greenhouse gas emissions continue on their projected trajectory. Ocean acidification has the potential to cause serious problems for a number of shell-building organisms including many newly discovered bottom-dwelling species. WWF-Australia's ROB NICOLL says rising CO_2 levels are already reducing the average shell weights of a some tiny but important animals.

THE SOUTHERN OCEAN represents around ten per cent of the world's ocean surface and covers an area of almost 35 million square kilometres. Isolated by ice, wind and wild seas, it is one of the world's most unspoiled environments.

This unexpected beauty of the Southern Ocean also supports some of the most biologically productive regions of the world's oceans and is home to some of the most fascinating creatures on our planet.

This is also where waters from all the major ocean basins are linked and the majority of the deep ocean waters that drive the global oceanic conveyor belt are formed. It has a unique and vital role in influencing the world's oceans and climate.

Both polar regions act as "heat sinks" that affect the entire world's climate and they are warming faster than other areas of the world.

The Southern Ocean is one of the major sinks of atmospheric CO_2 accounting for more that 40 per cent of the annual mean CO_2 uptake according to the Scientific Committee on Antarctic research (SCAR).

ACIDIFICATION IN THE SOUTHERN OCEAN

The impacts of ocean acidification will be particularly acute in the Southern Ocean before any other region and are predicted to affect bottom-dwelling species in shelf areas within 20 years and phytoplankton and invertebrates with aragonite and calcite shells in water columns soon after.

Research is also showing that human-caused ocean acidification has contributed to reduced calcification in Southern Ocean planktonic foraminifera (small free-swimming animals with shells). One species is already showing a 30-35 per cent reduction in the material it can form into a shell. Some of the minerals used for shellbuilding by tiny creatures have different properties. Aragonite dissolves more easily than calcite and therefore species that make use of aragonite shells or structures are under greater threat than those that form calcite shells or structures.

In addition to the overall acidity of sea water the depth and therefore the pressure of water is also important to calcifying organisms. Below certain depths the dissolution of calcium carbonate increases dramatically. This boundary is called the lysocline. Above the lysocline the water is supersaturated with calcite or aragonite and calcium carbonate formation is encouraged. Below it, the formation of calcite decreases dramatically. Notably, acidification of the ocean will lead to the lysocline becoming shallower, raising concerns for the health of deep sea corals and other bottom-dwelling invertebrates.

In areas of high seasonality such as that in the high-latitude Southern Ocean, aragonite saturation thresholds may be reached in the colder winter months by approximately 2040 and it is possible that the entire Southern Ocean surface will be under-saturated for aragonite by 2100.

ACTION ON ACIDIFICATION

The scientific community has intensified its research into this area, but knowledge is still limited.

WWF continues to call upon countries to make Antarctic research programs a priority to fill in the gaps surrounding what we know about the impacts of Southern Ocean acidification. These gaps include; impacts of ocean acidification over the long term; impacts on non-calcifying organisms; impacts of acidification on other biological processes besides calcification in invertebrates and vertebrates, and effects of acidification on recovery rates for vulnerable marine ecosystems such as cold water corals. ○

ROB NICOLL is WWF-Australia's manager of Antarctic and Southern Ocean Initiative.

The bottom of the food chain

Photo: NASA's Earth Observatory

This satellite image shows phytoplankton in the ocean around New Zealand. Phytoplankton is the bottom of the food chain in the ocean, indirectly supporting the entire fish population. Its photosynthesis also absorbs enormous amounts of CO_2. Understanding how much phytoplankton there is and how it behaves is important for planning sustainable fishing and also for predicting future levels of greenhouse gases in the atmosphere.

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The picture

Great catch – a thing of the past?

WHILE THE EXTENT of ocean acidification caused by carbon emissions is still being studied, scientists agree that it already threatens a broad range of marine species, from microscopic plankton communities to larger fish that feed upon them.

A giant halibut caught near the Orkney Islands in 1919, while Black Hawk was supporting the sweeping of the North Sea mine barrage. This one fish was sufficient for a meal for the entire crew.Note that a smaller, darker colored, halibut is also attached to the line.

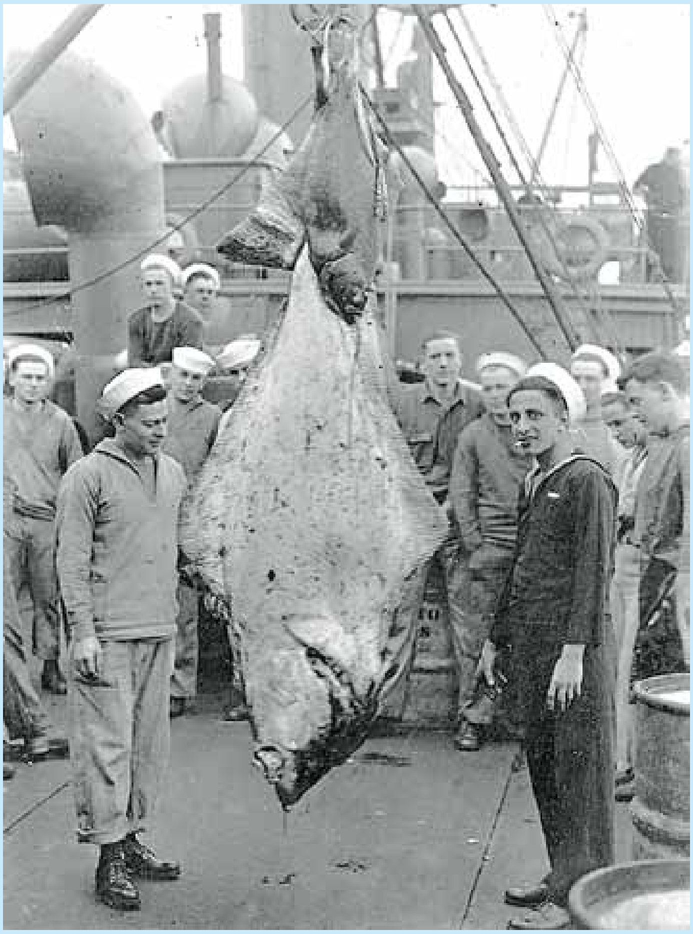

Photo: U.S. Naval Historical Center Photograph

WWF

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To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.

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