An Ecosystem Approach to Management of Seamounts in the Southern Indian Ocean

Volume 2 – Anthropogenic Threats to Seamount Ecosystems and Biodiversity

Edited by François Simard and Aurélie Spadone

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This paper is to be read in conjunction with two others: one giving an overview of seamount ecosystems and biodiversity (Volume 1) and one on a legal and instituional gap analysis (Volume 3).

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Foreword

Seamounts, underwater mountains rising from the seafloor, are abundant features of the world's oceans and as such are one of the most common oceanic ecosystems in the world. Known to be hotspots of biological activity and diversity, seamounts are globally important for marine biodiversity and play a vital role in marine food webs. Marine mammals, migratory fish and seabirds, for instance, are largely dependent on them for food. To date, the limited understanding we have of the marine fauna associated with seamounts indicates that many species grow and reproduce slowly and are thus highly vulnerable to overexploitation. One of the main barriers to sustainable management of seamount ecosystems and conservation of marine biodiversity in the high seas is a lack of knowledge about these fragile ecosystems.

Within the framework of its medium-size UNDP-GEF Seamounts project ('Applying an ecosystem-based approach to fisheries management in the high seas: focus on Seamounts in the southern Indian Ocean'), IUCN has coordinated the compilation of a paper examining existing and potential future threats of human activities to seamount ecosystems and biodiversity located in Areas Beyond National Jurisdiction (ABNJ).

The present document is to be read in conjunction with two companion papers: an Overview of Seamount Ecosystems and Biodiversity (Volume 1, authored by Alex Rogers), and a Legal and Institutional Gap Analysis (Volume 3, authored by Robin Warner, Philomène Verlaan and Gail Lugten). These three volumes – which form the series 'An Ecosystem Approach to Management of Seamounts in the Southern Indian Ocean' – serve as a basis for the development of a road map towards the sustainable use and conservation of biodiversity in the Southern Indian Ocean.

In addition to being major outcomes of the project, these volumes were used as background papers for two important workshops: a Governance workshop organized jointly with the ASCLME Project in Rhodes University, Grahamstown, South Africa, in June 2011, and a Management workshop that took place in Rome, Italy, in July 2012.

As part of the scientific component of the project, two research expeditions were conducted on seamounts of the South West Indian Ridge. The first one, which took place in 2009 aboard the R/V *Dr Fridtjof Nansen* as part of the EAF-Nansen project, studied the pelagic fauna (in the water column) associated with seamounts, while the second expedition, aboard the RRS *James Cook* (funded by the Natural Environment Research Council, NERC) in 2011, focused on the benthic realm (on the seafloor). By conducting some of the very first assessments of seamount ecosystems, the project created a vital baseline on the environmental status of seamounts from which future trends and impacts can be monitored. One characteristic of deep-sea ecosystems is the slow growth rate of the species associated with them; it is likely that these communities will recover only very slowly, if at all, from ecological damage such as overexploitation of marine resources or habitat destruction.

The ecosystems in ABNJ, including seamounts, are subject to negative impacts from human activities in many sectors. Whereas fishing activities are widely recognized as the most significant threat to these ecosystems, the threats resulting from the complete range of human activities in these areas have to be taken into account. The cumulative effects of those threats should be considered so as to be able to improve biodiversity conservation and find ways towards sustainable management of marine ecosystems.

Chapter 1 (by Philomène Verlaan) of this volume presents the overall context of anthropogenic threats to seamount ecosystems and biodiversity, and examines the non-fisheries threats to seamount ecosystems in ABNJ. Chapter 2 (by Garry Preston) then goes on to describe the threats from fisheries and aquaculture.

François Simard & Aurélie Spadone

IUCN Global Marine and Polar Programme

Disclaimer: Any opinions or views expressed in the following chapters are those of the authors and others cited therein as appropriate and do not imply any opinion or views whatsoever by or on the part of IUCN.

Executive Summary

The individual and cumulative threats to and effects of the full range of human activities on marine ecosystems and biodiversity in general, and seamounts in particular, in areas beyond national jurisdiction (ABNJ) are still largely unknown. These threats and their effects must be taken into account in order to be able to develop a robust, holistic ecosystem-based management scheme. This paper compiles and examines existing and potential future threats to seamount ecosystems and biodiversity located in ABNJ of the Indian Ocean. It is also intended to serve as a template for anthropogenic threat analyses of other seamount ecosystems elsewhere. Hence the scope of the present study includes actual and imminent threats to these areas as well. An institutional and legal gap analysis complements this paper. The reader is referred to this companion paper as appropriate.

Ecosystems and biodiversity must not be conflated. They play interactive but distinct roles in the marine environment. Biodiversity is the fundamental component of ecosystems, and a variety of ecosystems is included in the concept of biodiversity. Biodiversity provides options for organisms to respond to environmental challenges – such as those posed by the activities addressed in this paper – by maintaining their variability. To function best, biodiversity requires healthy ecosystems and *vice-versa*. Maintenance of biodiversity is essential to ecosystem stability. Loss of biodiversity can temporarily or permanently move an ecosystem into a different set of biogeochemical conditions, and lead to – at best – changes and – at worst – disruption of or reduction in the ecosystem's effective operation.

Many different mechanisms and ecosystems are responsible for the origin and maintenance of different aspects of biodiversity. They are all important to one or more species at one or more points in their life cycle. Marine ecosystems are numerous and varied, they operate on several temporal and spatial scales, and they are all crucial to marine biodiversity.

The activities posing actual or potential threats to seamount biodiversity and ecosystems are grouped into three categories. All activities physically conducted here will involve ships. Activities common to the use of all ships (category 1) are distinguished from activities for which the ship serves primarily as a platform (category 2). Category 3 covers activities that do not involve ships but that actually or potentially affect seamount biodiversity and ecosystems, including land-based activities.

From an ecosystem-based standpoint, categories 1 and 3 represent an underlying chronic set of threats, superimposed on which are acute, and potentially chronic, threats from category 2. None of the activities operate in an otherwise unstressed (threat- and effect-free) environment. Anthropogenic threats and their effects can and often do interact, with cumulative and synergistic adverse consequences for seamount biodiversity and ecosystems. Therefore none of the activities should be considered in isolation in assessing its implications for seamount biodiversity and ecosystem health.

The threats to seamount biodiversity and ecosystems fall into one or more of the following four overarching categories:

1. Pollution
2. Habitat destruction, degradation and fragmentation
3. Overexploitation
4. Invasive alien species (IAS).

Although the detailed interaction – feedback loops – among this quartet of fundamental threats is poorly understood, they also usually overlap in and exacerbate their individual deleterious effects on seamount ecosystems and biodiversity. It is highly likely that their detrimental effects are also synergistic and cumulative. The ultimate results of pollution, overexploitation and IAS are to degrade, fragment and eventually destroy seamount habitats, and thus their biodiversity and eco-systems on an oceanic, i.e., basin-wide, scale.

Ecosystem change in response to threats is often neither linear nor gradual. It tends to occur abruptly or accelerates once a threshold is crossed. This threshold is called the tipping point. After the tipping point has occurred, recovery or rehabilitation of the ecosystem is virtually impossible. Even if it were possible, it would be prohibitively expensive. The occurrence of tipping points in the marine environment is at present unpredictable.

Seamount ecosystems are particularly fragile and vulnerable to anthropogenic threats. Any additional or new activity, or the intensification of an ongoing activity, could become the tipping point for the collapse of a seamount ecosystem. At present an objective comparator of the threats and effects associated with the activities in this regard is lacking. This fundamental knowledge gap would be filled by a mechanism to improve the predictability of the tipping point trigger(s) and to improve the quantification of the risks thereof for seamount ecosystems.

Inside a bluefin tuna cage. © Marco-Carè/Marine Photobank

Chapter 1 – Non-Fisheries Threats

Author: Philomène Verlaan

I. Introduction

A. Background

The International Union for Conservation of Nature (IUCN) and its members have a long-standing commitment to achieving effective protection, restoration and sustainable use of biological diversity and ecosystem processes on the high seas. This commitment was reiterated at the 2008 IUCN World Conservation Congress. Through Resolution 4.031 'Achieving conservation of marine biodiversity in areas beyond national jurisdiction', IUCN members called, *inter alia*, for the promotion of arrangements, processes and agreements that ensure the consistent, coordinated and coherent application of the best conservation and governance principles and approaches, including integrated ecosystem-based management and the precautionary approach.

As part of this mandate, IUCN, in partnership with the United Nations Development Programme (UNDP), developed a medium-size project entitled 'Applying an ecosystem-based approach to fisheries management: focus on seamounts in the southern Indian Ocean', which was approved by the Global Environment Facility (GEF) in December 2008. The overarching project objective is to help improve marine resources conservation and management in the high seas. Biodiversity-rich areas, centred on seamounts, of the southern Indian Ocean (SIO) have been chosen to serve as a test case. The GEF SIO project has four main components:

1. Improve scientific understanding of seamounts in the SIO (two research expeditions, one each in 2009 and 2011);
2. Improve the governance framework (the main activity will be to undertake a legal gap analysis for the Indian Ocean and propose options for improvement);
3. Develop a model ecosystem-based management framework for the area; and
4. Communications and outreach.

B. Purpose of the paper

Fishing activities are widely recognized as the most significant threat to marine ecosystems and biodiversity, including seamounts, in areas beyond national jurisdiction (ABNJ), which include the high seas and the seabed beyond either 200 or up to ~350 nautical miles (nm) (depending in the latter case on the extent of the outer continental shelf). However, the individual and cumulative threats to and effects of the full range of human activities in ABNJ in general and seamounts in particular are not yet well characterized. These threats and their effects must be taken into account in order to be able to develop a robust, holistic ecosystem-based management scheme. Therefore one of the planned activities under this project is the preparation of a paper compiling and examining existing and potential future threats of human activities to seamount ecosystems and biodiversity located in ABNJ.

C. Scope of the paper

Although the initial purpose of this paper is to address the requirements of the GEF SIO project, it is also intended to serve as a template for anthropogenic threat analyses of other seamount ecosystems elsewhere. Hence the scope of the present study includes actual and imminent threats to these areas as well as to the specific GEF SIO project area. It is hoped that this more comprehensive approach will contribute to efforts underway to develop regulatory mechanisms to integrate and coordinate the environmentally responsible management of all human activities in ABNJ. This paper complements another commissioned for the GEF SIO project: an institutional and legal gap analysis. The reader is referred to this companion paper as appropriate.

This paper does not address the potential or actual (il)legality of the activities causing the threats, or any regulatory mechanisms either in place or proposed to deal with them. Nor does it propose any such mechanisms. Insofar as international law, including treaty law, provides definitions for the concepts and activities considered here, it will be adduced only to invoke those definitions.

With regard to activities that are at present still considered to be imminent, this paper does not address the likelihood of those activities and their concomitant threats materializing. The variables relevant to such an assessment are too susceptible to unpredictable shifts in politics and economics. Finally, this paper does not address the merits of the activities; it concerns itself only with the potential threats to seamount ecosystems and biodiversity posed by these activities and their effects. Whether the merits outweigh the threats is a different exercise, to which this paper hopes to contribute one set of considerations to be borne in mind when that exercise is undertaken. This paper sets out to present a baseline against which proposals for the coordinated management of seamount ecosystems and biodiversity can be developed and evaluated.

D. Ecosystems and biodiversity – context

Ecosystems and biodiversity must not be conflated. They play interactive but distinct roles in the marine environment. The Convention on Biological Diversity (CBD) defines biodiversity as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity between species, among species and of ecosystems" (Art. 2). The CBD defines ecosystem as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit" (Art. 2). While not ideal, these definitions suffice for present purposes: for biodiversity it highlights *variability*, i.e., active change, and for ecosystems it emphasizes dynamic interactions.

Biodiversity is the fundamental component of ecosystems, and a variety of ecosystems is included in the concept of biodiversity. Biodiversity provides options for organisms to respond to environmental challenges – such as those posed by the activities addressed in this paper – by maintaining their variability. To function best, biodiversity requires healthy ecosystems and *vice-versa*. Ecosystems too require biodiversity for their constituent communities and their interactions to operate effectively, which includes the ability for ecosystems to respond constructively to environmental challenges and changes. Maintenance of biodiversity is essential to ecosystem stability. Loss of biodiversity can temporarily or permanently move an ecosystem into a different set of biogeochemical conditions, and lead to – at best – changes and – at worst – disruption of or reduction in the optimal operation of the ecosystem.

Marine ecosystems can be broadly divided into 'static', i.e., more or less fixed to or closely associated with a solid surface, and 'mobile', i.e., found in the water-column as a functioning unit unattached to any fixed substrate. Seamounts host both types of ecosystems. Seamounts also serve as essential focal areas for maintenance of healthy biodiversity and of ecosystems that do not fall neatly within either of those two overarching categories or the static-vs.-mobile ecosystem dichotomy. These include areas where species aggregate to breed, spawn, feed, rest, seek refuge, just normally live in large numbers (school), and migrate. They also include "ocean triad" areas, where physical processes combine to "enrich, concentrate and retain" (Wurtz, 2007) various species and communities. Most – if not all – of these seamount ecosystems not only have highly localized species, they are also high in endemics, i.e., they have species found only at one restricted location.

It is becoming increasingly clear that many different mechanisms and ecosystems are required for the origin and maintenance of different aspects of marine biodiversity. They operate on several temporal and spatial scales and are all important to one or more species at one or more points in their life cycle. All are essential for marine biodiversity.

E. Approach

To minimize overlap between the effects of the threats and facilitate both the present analysis and the eventual broader utility of this study, the activities posing actual or potential threats to seamount biodiversity and ecosystems are grouped into three categories.

Trawler and seabirds interaction, Western Cape, South Africa. © LucyKemp/MarinePhotobank

All activities physically conducted in and around seamounts will involve ships. Threats from and effects of activities common to the use of all ships (category 1) are distinguished from those threats and effects deriving from activities for which the ship serves primarily as a platform (category 2). However, not all activities that actually or potentially affect seamount biodiversity and ecosystems involve ships. Category 3 covers threats and effects from this last group, which includes land-based activities.

In taking an ecosystem-based view, the first and third categories represent an underlying chronic set of threats, superimposed on which are the acute – and potentially chronic – threats from the second category. None of the activities operate in an otherwise unstressed (threat- and effect-free) environment. Hence, none of the activities should be considered in isolation in assessing its potential consequences for seamount biodiversity and ecosystem health. Thus, for example, the companion institutional and legal gap analysis should consider the effects of these activities in light of the three categories of threats analysed here.

F. Acknowledgement of sources and references

I am indebted to all the authors listed in the references (Part VI). They have not, because of the particular requirements and constraints of the present paper, other than for direct quotes, been individually credited at the point(s) where their work has been referred to or their ideas invoked. Any errors in my interpretation of the excellent and extensive work listed in Part VI are entirely my own.

II. THREATS AND EFFECTS

A. Threats from activities common to all ships

1. Accidental and/or deliberate (operational) discharges from vessels of:

a. Anti-foulants

Fouling involves small, sedentary, burrow-dwelling or clinging organisms, such as algae, barnacles, and molluscs adhering to surfaces immersed in seawater. Anti-foulants are comprised within the concept of anti-fouling systems (AFS) under international law, which are defined in the International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS Convention) as "a coating, paint, surface treatment, surface or device that is used on a ship to control or prevent attachment of unwanted organisms". Annex 1 to the AFS Convention lists AFS to be prohibited or controlled, including organotin compounds and other anti-foulants that act as biocides, to be updated as necessary. Anti-foulants leach into the seawater, where they persist and probably bioaccumulate, causing adverse immune responses, and neurotoxic and deleterious genetic effects in non-target marine species, as well as killing them outright. Dissolved organotins and organotins adsorbed onto particles also accumulate in sediments, where they can contaminate and be toxic to benthic organisms and, on resuspension from the sediments into the water column, further contaminate the water column.

One of the most effective anti-foulants contains the organotin tributylin (TBT), shown to cause deformations in oysters and sex changes (imposex) in whelks (see also Section A (1) (g) on heavy metals). Imposex is associated with reduced reproductive potential and altered population structure in several species. Imposex is even found on the high seas; its incidence there is correlated with high-density shipping lanes. Bioaccumulating up the food chain, TBT reaches very high concentrations in top predators, such as dolphins, tuna and sharks. Described by Dr Laurence Mee as "probably the most toxic substance ever introduced deliberately into the marine environment" (Mee and Fowler, 1991), TBT degrades slowly (in sediments under oligotrophic water, degradation can take up to 87 years) and even its degradation products can harm a wide range of marine organisms.

Organic booster biocides, often based on copper metal oxides, are now being used as alternatives to organotin compounds in antifouling products, after restrictions were imposed on TBT use. However, one of the most commonly used biocides, Irgarol 1051, is known to inhibit photosynthesis and growth in marine algae at very low concentrations, and adversely affect primary productivity. Evidence of their toxicity to other non-target organisms, including phytoplankton and corals, is mounting, and these new anti-fouling compounds present an emerging threat to seamount biodiversity and ecosystems.

b. Bilge water, ballast water and associated sediments

Bilge water is a combination of rain-water, seawater, waste matter and oil seeping into lower interior spaces below deck. Ballast water is usually coastal water taken on board a ship in port, to stabilize an unladen or a lightly laden vessel during her voyage. Ballast water is discharged and exchanged for cargo at the destination port. Ballast water is used to maintain the essential operational and safety parameters for overall trim, stability, and hull integrity of the ship. It is dangerous for a ship to be either too low or too high in the water. Ballast water may be carried in either dedicated or 'segregated' ballast tanks, used exclusively for that purpose, or in the cargo tanks of tankers. Ballasting cargo tanks is now less common and usually found only when the vessel is putting on extra 'heavy ballast' or 'storm ballast' in order to deal with especially heavy seas. The principal difference between bilge water and ballast water is that ballast water contains living organisms, whereas bilge water does not, because it usually contains too many contaminants. Bilge water represents a threat whose effects are similar to those of liquids contaminated with garbage, heavy metals, oil and oily wastes, persistent organic pollutants (POPs) and sewage (see also Section A (1) (d, f-i)).

Ballast water can contain sediment if it is taken onboard in water that contains suspended sediment. The sediment settles on the bottom of the tanks and is physically shovelled over the side of the ship directly into the ocean when the ballast water is discharged. These sediments and ballast water can contain a wide range of live marine and estuarine flora and fauna. Their larvae, spores and juveniles can survive the long distances they are transported on board vessels. Ballast water and the associated sediments are important vectors for the transfer around the world of harmful aquatic organisms and pathogens, known generally as invasive alien species (IAS) – see Section A (5). Ballast water remains of the greatest concern because of the huge quantity of water transported and the wide variety of organisms carried.

The International Maritime Organization (IMO) states that "the problem of invasive species is largely due to the expanded trade and traffic volume over the last few decades. The effects in many areas of the world have been devastating. Quantitative data show the rate of bio-invasions is continuing to increase at an alarming rate, in many cases exponentially, and new areas are being invaded all the time. Volumes of seaborne trade continue overall to increase and the problem may not yet have reached its peak. Examples include the introduction of the European zebra mussel (*Dreissena polymorpha*) in the Great Lakes between Canada and the United States, resulting in expenses of billions of dollars for pollution control and cleaning of fouled underwater structures and waterpipes; and the introduction of the American comb jelly (*Mnemiopsis leidyi*) to the Black and Azov Seas, causing the near extinction of anchovy and sprat fisheries" (IMO, 2010).

The International Convention for the Control and Management of Ships' Ballast Water and Sediments sets out to "prevent, minimize and ultimately eliminate" this transfer. Although it is not yet in force, guidelines for its implementation have already been promulgated and are steadily gaining acceptance. At present, the primary defence against IAS in all current ballast-water regimes, both voluntary and regulatory, is the requirement for an open-ocean exchange of ballast water. This constitutes a threat if it occurs near seamounts. See also Section A (1) (5) on IAS.

c. Cargo

Of primary concern here is the accidental loss at sea of cargo, and particularly of containers, which can be 20 feet to 40 feet long and 8 feet high. Modern container ships stack much of their load high on the open deck. Despite stringent loading and fastening regulations, it is estimated that 2,000-10,000 containers are lost overboard every year, usually during storms. Overall, fewer incidents of loss occur, but when one does, more containers are lost because ships are much bigger and the load is stowed wider and higher. It can take only one container to break free, or to collapse, to trigger a cascade of containers over the side.

The length of time a container will float depends on the type of cargo, and the type, permeability, and durability of the container. Some containers and cargoes sink immediately, while others may float for months or years. Empty freight containers are not watertight and will quickly sink. Containers filled with lightweight, low-density and buoyant cargoes can float for years – even when holed and waterlogged. A reefer may float until it is broken up by sea state and wave action. A low-density cargo may float until the doors are damaged and opened by sea action. While afloat, containers lost at sea may not be easily visible and could constitute a shipping hazard. Container and cargo losses are not systematically monitored.

The threats posed by and the effects of cargo on seamount biodiversity and ecosystems depend on the nature of the cargo. (See also discussion of cargo residues and cargoes containing hazardous substances under Section A (1) (d) on chemicals, and of spoilt cargo under Section A (1) (f) on garbage). The threats and effects of substances and materials introduced deliberately or accidentally into the marine environment discussed in this paper are unlikely to differ substantially if the materials or substances find their way into the ocean as components of a vessel's cargo lost overboard rather than by direct discharge (or dumping). With regard to containers and other cargo assemblages that remain afloat for long periods, they can also serve as vectors for IAS (see also Section A (5)). One positive effect is that floating containers and cargo provide oceanographers with useful empirical information in their work on tracking global ocean currents.

d. Chemicals and other harmful commercial products and substances

Some 250,000 anthropogenic chemicals are present in the marine environment, and every year new chemicals are introduced to the market, whence many of them eventually enter the sea. These substances have properties or produce effects that are environmentally hazardous, such as flammability, acute and chronic toxicity, corrosivity, reactivity, bio-accumulative propensity, and resistance to degradation. They can kill organisms directly, but equally – if not more – detrimental in the long run is the undermining of ecosystem integrity due to the effects of chronic exposure of organisms to these chemicals, which can impair immune systems, cause cancer and developmental problems, and reduce reproductive success.

They fall under the category of 'harmful substances' defined in Article 2 of the International Convention for the Prevention of Pollution from Ships (MARPOL) as "any substance which, if introduced into the sea, is liable to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the sea, and includes any substance subject to control by the present Convention". They are governed by Annexes II and III of MARPOL.

Within this group and governed by MARPOL Annex II are also included three categories of wastes: washings of tanks containing noxious liquid substances (NLS); cargo residues of NLS; and dirty ballast. The term NLS encompasses any bulk liquid chemical that does not meet the definition for oil as defined in MARPOL Annex I (see Section A (1) (h) on oil) and includes petrochemicals, solvents, waxes, lubrication oil additives, vegetable oils and animal fats. Of these three categories, washings of tanks containing NLS often occur, whereas cargo residues and dirty ballast occur rarely. Cargo residues usually consist of a single NLS. Dirty ballast contains very low concentrations of NLS, but as most chemical ships have segregated ballast tanks or double hull spaces, ballast water contaminated with NLS is very rare (see also Section A (1) (b) on bilge water and ballast water). NLS cargoes are categorized by the International Bulk Chemical (IBC) Code in terms of the degree of hazard each individual cargo poses to marine resources or human health. According to this categorization, Annex II prohibits, limits or permits the discharge into the marine environment of NLS substances depending on the degree of hazard to either marine resources, or human health, or amenities. See also, with regard to chemical munitions and radioactive waste, Section B (4) and (7) on dumping and military activities, respectively.

Even in the open sea, as with garbage, oil, POPs and sewage (see Section A (1) (f, h-j) respectively), when vessels congregate or pass regularly or often through or over a particular biologically diverse area, such as a seamount, even operational discharges of chemicals, let alone accidental spills, cannot be assumed to be environmentally benign. The risk to seamounts of ship-source chemical pollution is exacerbated by atmospheric deposition of chemicals; this airborne source has been estimated at ~33% of chemical inputs to the ocean. The surface micro-layer of the open ocean also concentrates pollutants, often many times higher than in the underlying water column. Larvae collect in the micro-layer, and they are more sensitive to pollutants than adults.

e. Exhaust and other gaseous emissions

Ship emissions include CO_2*, hydro-chlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs)*, methane (CH_4)*, nitrogen oxides (NOx) including N_2O (nitrous oxide)*, ozone-depleting substances (e.g., halons, chlorofluorocarbons (CFCs)), particulate matter, perfluorocarbons (PFCs)*, sulphur hexafluoride (SF_6)*, sulphur oxides (SOx) and volatile organic compounds (VOCs) such as industrial solvents. (The asterisk (*) identifies major greenhouse gases (GHGs) under the Kyoto Protocol, a supplement to the Framework Convention on Climate Change, an international treaty to regulate emissions of GHGs). By 2020, emissions of SOx from international shipping are estimated to increase by 42% and of NOx by 66%. At present, ship emissions are most evident in the northern hemisphere, where the majority of shipping traffic occurs, especially along the main shipping lanes, and within 400 km of the coast, where about 70-80% of the emissions occur.

The type and volume of ship emissions are governed by engine age and type, weather conditions, fuel quantity and type, ship operational mode, and use of any emission reduction technology. Though not negligible, shipping accounts for about 2% of CO_2 production, which is ~three to five times less CO_2 than road and rail transport produce and between twenty and thirty times less than air transport produces in transporting one tonne of cargo over one kilometre. Annex VI of MARPOL addresses emissions to the air from ships.

Vessel emissions exacerbate climate change through CO_2 and other GHG production, decrease ambient air quality and, by increasing cloudiness through sulphur aerosol production, can alter solar radiation energy. Chemical reactions in the atmosphere can convert emissions of NOx and SOx into, respectively, nitric and sulphuric acids. This process can take several days, during which these pollutants can travel thousands of kilometres from their original sources. Both NOx and SOx are more water-soluble than CO_2 and thus contribute significantly to increasing the acidity of rainwater. Where this acid rain falls on the ocean, it exacerbates the ocean acidification caused there by excessive production of CO_2 from a variety of mostly anthropogenic, land-based sources. (See also Section C (1) on anthropogenic climate change, which addresses, *inter alia*, ocean acidification.)

f. Garbage

Annex V of the MARPOL Convention defines garbage as including all kinds of food, domestic and operational waste, excluding fresh fish, generated during the normal operation of the vessel and liable to be disposed of continuously or periodically. Garbage also includes cargo residues and cargo-associated wastes. The guidelines to MARPOL Annex V provide further details on what constitutes garbage.

Discharge into the sea of spoilt cargo is an environmental problem, but spoilt cargo is not defined in the relevant Conventions or the guidelines. Circular Letter 2074 of 20 July 1998 by IMO (available at: **www.imo.org**) notes that it could be described as cargo which has changed during the voyage such that it no longer meets its original specifications, is no longer marketable and usually consists of agricultural products or raw materials from mining or quarrying. Unless it is considered to be garbage generated during normal ship operations, it is subject to the ocean dumping rules (see Section B (4)).

The threats posed by and the effects of garbage and spoilt cargo on seamount biodiversity and ecosystems depend on the nature of the cargo – see also discussion of cargo above under Section A (1) (c) and of the threats and effects of the other substances and materials introduced deliberately or accidentally into the marine environment discussed in this paper. The threats and effects of these materials and substances are unlikely to differ significantly whether they find their way into the ocean as spoilt or lost cargo or by direct discharge. Even in the open sea, as with chemicals, oil, POPs and sewage (see Section A (1) (d, h, i, j) respectively), when vessels regularly or often congregate in or pass through or over a particular biologically diverse area, such as a seamount, operational and accidental discharges of garbage there cannot be assumed to be environmentally benign.

Garbage is also a subset of marine litter or marine debris, which is addressed in Section C (3). Annex V of MARPOL also applies to plastic, the disposal of which anywhere at sea is prohibited. Of the various garbage categories, plastic poses the greatest danger to seamount biodiversity and ecosystems (see Section C (3) on marine debris/litter for discussion of threats posed by plastics).

g. Heavy metals

The term 'heavy metal' is often used interchangeably with 'trace metal'. Although neither term is entirely descriptively or scientifically correct, both refer to a group of elements that exhibit metallic properties, and include biologically essential and non-essential trace/heavy metals. All are potentially toxic to living organisms if biologically available (this depends on their speciation, which varies with the element concerned) at concentrations above a certain level, which varies depending on the organisms involved. The principal essential trace metals, in approximate order of biological importance, are the transition elements Fe>Mn>Zn>Cu>Co>Ni.

Primary producers extract them from seawater, where they are soluble, and biologically available, as divalent cations. The most important non-essential elements in this context, for which – so far – only properties toxic to marine organisms have been observed, include arsenic (As, a metalloid), cadmium (Cd), lead (Pb), mercury (Hg), and tin (Sn).

Marine ecosystems and biodiversity are especially susceptible to the harmful effects of heavy/trace metals. Marine organisms are in close and prolonged contact with the soluble forms of the metals throughout the water column and in the interstitial water of sediments. Once introduced into the food web, these metals can bioaccumulate and biomagnify up the food chain, increasing the organism's exposure risk by ingestion. They also accumulate in sediments, whence they can be resuspended, thereby re-entering and re-polluting the water column.

In marine organisms heavy metals can inhibit growth, cause disease, developmental aberrations and death, change biochemical and physiological functions and behaviour, impair immune systems and adversely affect reproduction. Benthic and near-surface organisms are likely to be most at risk, with larvae being especially vulnerable. Photosynthesis can be inhibited in phytoplankton. For the effects of tin (Sn) in particular, see also Section A (1) (a) above, on antifoulants (TBT). For heavy metals in general, see also under Section B (4) on ocean dumping,

h. Oil

This short word covers a large and complex group of harmful liquid, gaseous and solid hydrocarbon compounds, including polycyclic aromatic hydrocarbons (PAHs, the most toxic, whose toxicity also varies with the bioavailability of the different PAH species). This group is addressed by MARPOL Annex I and includes crude oil, refined petroleum products (e.g., gasoline, diesel fuel) and by-products, ships' bunkers, oily refuse, oil mixed in waste, and six categories of waste generated in ships' engine rooms and cargo spaces, i.e., oily bilge water, oily residues (sludge), oily tank washings (slops), dirty ballast water, scale and sludge from tanker cleaning, and oily mixtures containing chemicals. The first two of the latter six categories of oily wastes are found in all vessels; the next three are found in cargo spaces of oil and oil product tankers, and all involve cargo residues. Oily tank washings and recovered cargo residues (slops)

Oil and gas tankers. © Wolcott Henry/Marine Photobank are the most common of the six. The 'dirty ballast water' category comes from the now almost extinct non-segregated ballast tankers, as well as on the very rare occasions when tankers must take on additional ballast water to increase their draft in particularly severe weather (see also Section A (b) above on bilges and ballast water), and when tankers of a particular design conduct operations under certain established exceptional conditions. The category 'scale and sludge from tanker cleaning' arises from cleaning operations prior to surveys or repairs. The sixth category, 'oily mixtures containing chemicals', arises either from cleaning of engine room machinery and spaces, or from washing tanks for oil or for products with water mixed with chemical substances. See also Section A (1) (b-d) above.

Although accidental discharges – usually in the form of oil spills from foundering or wrecked tankers – capture the most attention, they are rare. Operational discharges are the most important chronic and continuous sources from shipping of oil to the oceans. Illegal operational discharges are a worldwide problem, especially on the high seas, where surveillance and detection are generally absent.

Oil can evaporate, dissolve, emulsify into small drops, and form tar balls. Made up of the heavy viscous fraction of the oil, tar balls float in the sea and drift with currents and tides. Dissolution of oil compounds, particularly of PAHs, results in their incorporation into water-soluble fractions, which are taken up by marine organisms and constitute a primary source of toxic exposure, especially at lower levels of the food web. Bioaccumulation by filter feeders and biomagnification up the food chain intensifies the toxic effects of oil on organisms that concentrate these contaminants in their tissues or on their predators. The densest oil fractions can sink to the bottom and contaminate the benthos and sediments.

Sediments can constitute a particularly long-lived source of oil-based contaminants, and especially of PAHs, where their concentration can be 100 times higher than in the overlying water column. They adsorb easily onto particles because of their hydrophobicity, and in this form are even more resistant to degradation than dissolved PAHs.

Oil discharged into the sea adversely affects the marine environment and marine organisms throughout the food web, from phytoplankton to marine mammals. The specific effects of oil will vary, depending on the form(s) in which it enters the ocean, the location of the discharge, and the weather conditions. For example, when oil floats on top of the sea, less light penetrates into the water, limiting photosynthesis by phytoplankton, the base of the marine food web. Eggs, larvae, fish and invertebrates in the water column, especially near the surface, can also be adversely affected. Larvae are more vulnerable as they are less able to detect and avoid the oil than adult fish and invertebrates. Eggs floating just under the sea surface are particularly susceptible to contamination.

Exposure to oil reduces the insulation of seabird plumage and marine mammal fur, increasing their vulnerability to temperature fluctuations and hypothermia. Birds become less buoyant and their flight is impaired, making it difficult or impossible to forage and escape from predators. Oil ingestion in seabirds and marine mammals (e.g., through preening by birds, consumption of contaminated prey) can damage kidneys, alter liver function and irritate the digestive tract, leading to dehydration and metabolic and hormonal imbalances. Prolonged exposure to low levels of oil can adversely affect survival and reproduction of seabirds, marine turtles and marine mammals.

Sub-lethal toxicity is a pernicious effect of oil contamination; for example, PAHs appear to induce genetic damage, even at environmentally low concentrations. The water-soluble fraction of PAHs accumulates in membrane lipids, where it disrupts membrane-associated biochemical, physiological and immunological functions. Chronic exposure to oil pollutants can increase production of free radicals, leading to oxidative stress. Impaired behavioural responses, such as lower feeding rates and delayed escape manoeuvers, are also observed. These effects can all lead to changes in vital functions that affect the survival and ability to reproduce of the affected organisms and culminate in damaging their populations, communities and eventually the ecosystem as a whole.

Accidental oil spills and chronic discharges can adversely affect open-ocean oceanographic features where biological activity is concentrated, such as seamounts, as well as convergence zones, gyres and eddies, which can concentrate pollutants (see also Section C (3) on marine debris/litter). As with chemicals, garbage, POPs and sewage (see Section A (1) (d, f, i, j) respectively), even in the open sea, when vessels congregate regularly and often in a particular biologically diverse area such as over a seamount, operational discharges there cannot be assumed to be environmentally benign.

i. Persistent organic pollutants (POPs)

These are carbon-based (hence 'organic'), semi-volatile, high-molecular-weight (especially dangerous at >236 g/mol) and low-water-soluble chemical substances that become widely distributed throughout the marine environment, far from their point of origin, and then persist there for many years. For example, one POP (PFOS, see list below) has shown no degradation under any environmental condition tested. POPs resist degradation and bioaccumulate, especially in fatty tissue (a consequence of their high lipid solubility), where their concentrations can magnify through the food web up to 70,000 times background levels. POPs are frequently halogenated, usually with chlorine. The more chlorine groups a POP has, the more resistant it is to degradation. They tend to volatilize in hot regions and accumulate in cold regions, where they condense and remain, exacerbating their noxious effects on these fragile marine environments because degradation processes are slower at low temperatures. Deep-sea oceanic food webs may be contaminated by POPs as well, as deduced from the presence of brominated flame retardants (BFRs) in sperm whales, which feed in deep offshore waters.

The Convention on Persistent Organic Pollutants governs the following POPs, which are usually divided into the following three categories:

- **Pesticides:** aldrin, chlordane, **d**ichloro**d**iphenyl**t**richloroethane (DDT), dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene, chlordecone, alpha hexachlorocyclohexane, beta hexachlorocyclohexane, lindane, pentachlorobenzene;
- **Industrial chemicals:** hexachlorobenzene, polychlorinated biphenyls (PCBs), hexabromobiphenyl, hexabromodiphenyl ether and heptabromodiphenyl ether, pentachlorobenzene, perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOS-F), tetrabromodiphenyl ether and pentabromodiphenyl ether; and
- **By-products:** polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/PCDF), and by-products from the two other categories.

They have acute and chronic toxic effects on marine organisms. Fish, predatory birds and marine mammals are high up the food chain and so absorb the greatest concentrations. Low PCB levels have also been found in Mediterranean loggerhead turtles (*Caretta caretta*), suggesting that POPS may also affect at least one of the six endangered species of marine turtle. In marine mammals, certain POPs (especially BFRs), once absorbed, may be passed from mother to young through the placenta and milk. Specific adverse effects of POPs can include cancer, allergies and hypersensitivity, damage to the central and peripheral nervous systems, reproductive disorders, and disruption of the immune system. Some POPs are endocrine disrupters, which, by altering the hormonal system, can damage the reproductive and immune systems of exposed individuals and their offspring, as well as have developmental and carcinogenic effects. They can kill organisms directly and undermine ecosystem integrity. Although POPs are only a small part of the approximately 250,000 anthropogenic chemicals present in the marine environment, they add substantial stress to ecosystems already compromised by other pollutants. See also Section A (1) (d) above on chemicals and other harmful commercial products and substances.

j. Sewage

The discharge of raw sewage into the sea can create a health hazard from pathogens in the sewage, lead to changes in local microbial, phytoand zoo-plankton communities, cause localized oxygen depletion (hypoxia) because of its elevated nutrient content (especially N and P), and be visually unpleasant. If the hypoxic area intersects the ocean floor, benthic organisms, especially less mobile ones, may die. It is still generally considered that the open oceans are capable of assimilating and dealing with raw sewage through natural bacterial action. Annex IV of MARPOL, which deals with sewage, prohibits ships from discharging sewage within a specified distance (usually 12 nm) from the nearest land, unless they have in operation an approved treatment plant. However, as with chemicals, garbage, oil and POPs (see Section A (1) (d, f, h, i), respectively), even in the open sea, when vessels regularly or often congregate in or pass through or over a particular biologically diverse area, such as over a seamount, disposal of sewage there cannot be assumed to be environmentally benign.

2. Anchoring

Anchoring physically destroys and alters habitat and habitat structure on the seafloor and harms or kills sessile, fixed and less mobile organisms in the anchor's path, through direct physical destruction by the anchor and its chain and through sediment clouds raised by anchoring that can smother such organisms nearby. If the seafloor is shallow enough, increased turbidity from the sediment clouds can reduce primary production, with all the concomitant adverse effects further up the food chain, for which phytoplankton form the base. The type and magnitude of the effects depend on size and type of anchor and the length of chain used, and whether the anchor and chain 'crab', i.e., move sideways in response to the vessel's movement under differing wind and sea states. Crabbing exacerbates the adverse environmental effects on the benthic communities and their habitat because a much larger area is affected.

Anchoring destroys both hard and soft substrata, and thereby the habitatof the organisms and communities that can only live in association with one or the other. Vulnerable hard substrata include, in particular, coral and associated ecosystems. With regard to soft (sediment)

Anchors physically destroy and alter seafloor habitat. © Daniel Sasse/Marine Photobank

substrata, the especial vulnerability of seagrass communities to anchoring must not be forgotten, as some seamount summits may be sufficiently shallow to permit their presence.

3. Collisions (ship strikes) with, e.g., marine mammals, sharks, turtles

Ship strikes are regularly reported from all the oceans. For the groups mentioned in the subheading above in particular, all of which are more or less endangered, ship strikes are a source not only of individual fatalities but also of an increased threat to the species as a whole. Insofar as members of these groups are known to congregate around seamounts, ship strikes there exacerbate their precarious survival status, which is already under stress from other threats addressed in this chapter (e.g., noise, pollutants, prey depletion) and in Chapter 2 on fisheries. Noise pollution (see also Section A (6)) may also increase the propensity for members of these groups to collide with ships; the animals may not be able to detect the noise of an approaching ship due to masking by other noise, or to distinguish between ship noise and other noises.

4. Grounding and shipwreck

Grounding is a threat in shallow water and could therefore be a problem where seamount summits are near the surface. Its effects are similar to those described in Section A (2) above for anchoring, namely to physically destroy habitats and their communities. Propeller scarring and abrasion by ships' hulls of the habitat are shallow-water physical threats that are also included in this category. Grounding is temporary, in that the vessel is able to free itself; however, the activities necessary to free the vessel will usually further destroy the benthic environment. Permanent grounding is treated as a shipwreck, and is discussed below.

Shipwrecks occur worldwide and it is estimated that since 1914 more than 10,000 ships have sunk to the seafloor through war and accidents. The locations of many of the vessels lost at sea are not known, especially of military vessels during World War II that were carrying radioactive or other hazardous materials. Where their locations are known, their propensity to be a source of, in particular, radioactive, chemical and heavy metal pollution is usually not investigated (see also Section B (7) on military activities).

The nature, scale and duration of the environmental effects of shipwrecks, especially in the deep sea and on seamounts, have not yet been extensively studied. Effects will to a certain extent vary with, and may be reasonably predicted from, the type of ship, her size and cargo, and the depth and latitude of the wreck (e.g., tropical or temperate or polar seas).

A ship foundered on a seamount will likely be a source of oil and other pollutants described in Section A (1) (a-j) above, as well as potentially a source of IAS (see also Section A (5)). A wreck can cause substantial benthic habitat and community destruction similar to that described for anchoring (see Section A (2) above and grounding in this sub-section). In the fullness of time, however, when all the pollutants have decayed, dissolved, become diluted or otherwise rendered harmless, and if IAS have not overwhelmed the native community, a wreck may end up serving as a useful source of hard – albeit different from the original – substratum, essentially becoming an artificial reef. This can be a valuable ecological contribution, because hard substrata are at a premium in the deep sea, where sediments dominate, even on seamounts. The hard substratum provided by the wreck, around which a community can re-establish itself, offers potential for reconstitution of the community originally destroyed by the wreck.

Although not yet in force, the 2007 International Convention on the Removal of Wrecks provides the legal basis for States to remove, or have removed, shipwrecks that may have the potential to adversely affect the marine environment, and to hold the ship owners responsible. Environmental criteria such as damage likely to result from the release into the marine environment of cargo or oil are also included. 'Removal' is defined as any form of prevention, mitigation or elimination of the hazard created by a wreck (Art. 1 (7)) and 'hazard' is defined as "any condition or threat that … may reasonably be expected to result in major harmful consequences to the marine environment" (Art. 1 (5)). The wreck will have to be disposed of in an environmentally responsible manner (see also Section B (11) on salvage). The Wreck Removal Convention applies to stranded (i.e., grounded, see above) ships (Art. 4 (a)) and to ships that are "about, or may reasonably be expected, to sink or to strand, where effective measures to assist the ship or any property in danger are not already being taken" (Art. 4 (d)).

5. Invasive alien species (IAS)

An alien species is "an organism, inclusive of parts, gametes or propagules, that may survive and subsequently reproduce, occurring outside its known ... native range, as documented in scientific publications … [and] whose population has undergone an exponential growth stage and is rapidly extending its range" (Galil *et al.*, 2008). A vector is "any living or non-living carrier that transports living organisms intentionally or unintentionally" (ICES, 2005).

Ships are important IAS vectors. The variety of means by which ships can spread IAS include:

- fouling on the outside of the hull;
- poorly maintained marine sanitation devices;
- water on decks;
- water in anchor lockers;
- lost cargo and cargo containers (see Section A (1) (c) on cargo, above);

- garbage (especially plastics (see Section A (1) (f) above on garbage and Section C (3) on marine debris/litter and derelict fishing gear);
- fouling on anchors and chains; and
- ballast water.

Bilge water, commonly confused with ballast water, is not a significant IAS threat because it is usually too contaminated. Ballast water is of the greatest environmental concern because of the huge quantity of water transported and the wide variety of organisms (protists, phyto- and zoo-plankton, invertebrates and fish) it carries (see also Section A (1) (b) above on bilge water and ballast water).

These non-indigenous plants and animals can adversely affect the habitats they invade in numerous, often interactive ways. Adverse effects of IAS, depending on the species, include:

- rapid reproduction (can spawn multiple times per season) to form very large populations that dominate the local community, altering food webs, habitat and ecosystem function;
- competition for food and habitat with, and preying on, native fish and invertebrate species, including their eggs and young, causing local extinctions during population outbreaks;
- formation of harmful algal blooms (HABs);
- cause of massive kills of marine life through oxygen depletion, release of toxins and/or mucus;
- contamination of filter-feeders, such as shellfish; and
- cause of severe fouling problems on infrastructure and vessels.

The adverse effects on biodiversity can be widespread and affect entire ecosystems. The establishment of IAS tends to homogenize species composition and lower the number of species, such that a few common species end up dominating a given community, with the loss of unique and distinctive species and traits that made up the original and particular biodiversity at that location. A well-known and sobering example of such a change in species dominance and then in the whole ecosystem is the shift in Black Sea plankton from crustacean communities to the IAS ctenophore (comb jelly) *Mnemiopsis leidyi*. This changed the fish communities feeding on the plankton, and eventually, together with pollution and overfishing, caused the fisheries to collapse.

The effects of IAS are felt in the water column and on the seafloor, on both hard and soft substrata. Competition for space on hard substrata, always at a premium in the sea, is a particular threat, to which seamounts are likely to be especially vulnerable.

6. Noise

Noise, as a form of energy, can constitute marine pollution within the definition of pollution set by the United Nations Convention on the Law of the Sea (LOSC). Given the steadily growing increase in anthropogenic noise levels in the ocean and the observed adverse effects on marine organisms, noise probably already meets the LOSC's criteria for pollution (see Part IV, Analytical Summary).

Anthropogenic noise in the ocean derives from activities such as:

- shipping (propellers, engines, machinery, and water flow over the hull of ships);
- oil and gas exploration (explosives, drilling, seismic air guns) and exploitation (drilling platforms);
- scientific research (sonar, seismic air guns, drill ships);
- military operations (sonar, weapons testing, explosives);
- offshore construction of facilities and their operation;
- dredging to lay pipelines and maintain shipping lanes; and
- acoustic deterrence and harassment devices.

These devices are so far most often used in a fisheries context and are probably the principal example of *deliberate* marine noise pollution. They are targeted at marine mammals but also adversely affect non-target species.

In some ocean basins, such as the North Atlantic, the level of ocean noise is estimated to be doubling every decade. In the northern hemisphere, overall ship noise at low frequencies (below 1,000 Hz) has increased by about 3 decibels (dB) per decade over the past 60 years. It now seems to be growing at 3-5 dBs/decade. The larger the ship, the noisier it will be, and ship size (tripling) and numbers (doubling within the next 20-30 years) are steadily increasing, principally in the commercial ship sector (cargo vessels, super tankers and cruise liners).

Sound travels about five times faster and over larger distances in the sea than in the atmosphere, especially at low frequencies and when channeled by temperature and pressure gradients. The effects of underwater noise can extend much further than similar noise levels produced on land. Particularly disruptive are the low-frequency sounds emitted during seismic surveys and sonar activity, as well as from distant shipping and construction, which radiate over very large areas over long periods of time, resulting in chronic exposure by marine organisms to noise pollution.

The most powerful noises (explosives, air guns, sonar) can injure (including causing temporary or permanent hearing loss) or kill organisms that are close enough to the source of the noise. Noise from other activities is not usually as loud, but it is more constant, and the resultant continuous and increasing background noise pollution of the ocean adversely affects marine organisms just as continuous and increasing background airborne noise pollution adversely affects terrestrial organisms, including humans. Continuous noise is a source of stress which has been shown to cause chemical changes that adversely affect growth, reproduction and resistance to disease in human and other terrestrial animals. It is unlikely to leave marine animals unaffected.

Marine animals, such as cetaceans, often have weak eyesight. Their world transmits light poorly and is largely defined by acoustic information, as it is for many deep-sea fish, which live in a world of darkness. They must rely on sound to communicate, coordinate their movements, navigate, investigate and use their environment, find prey and avoid hazards such as obstacles and predators. Under natural conditions, large cetaceans (including endangered species of balaenopteridae (e.g., fin whale)), communicate and orient acoustically over thousands of kilometres in the ocean. They are able to detect topographic features more than 500 km away.

Increasing levels of anthropogenic noise in the oceans act like smog for acoustically sensitive species, obscuring signals potentially critical to migration, feeding and reproduction. The masking effect of the increased ambient anthropogenic noise has already impaired long-range communication for mysticetes (baleen whales). Shipping noise, derived largely from propulsion, operates in the 20-200 Hz band, the dominant frequency used by baleen whales for communication. The communication difficulties caused for mysticetes by anthropogenic noise are exacerbated by their severe numerical depletion due to whaling. To reach their few remaining counterparts, they are obliged to communicate over much longer distances than their communication apparatus originally evolved to accommodate. Moreover, any hearing loss they might be suffering will further jeopardize their ability to function acoustically.

Other observed adverse effects of noise pollution include stranding and displacement from their normal habitat, tissue damage and mortality. Collisions with vessels (see also Section A (3) above) may be another consequence of noise pollution. Noise pollution may also adversely affect mating, feeding (e.g., ability to locate and capture prey), mother-young bonding, ability to detect and avoid predators and ships, growth and successful reproduction, and, ultimately, longevity. For marine mammals, at least, hearing is their primary sense underwater, as sight is ours on land. Their hearing plays a huge variety of crucial roles throughout their lifetime and an acoustically unpolluted environment is essential to their well-being and survival.

Although the effects of noise on marine mammals have been the focus of most research so far, other marine organisms are increasingly being shown to be not dissimilarly adversely affected by this form of pollution; they include sea turtles, fish, seabirds and some invertebrates, e.g., shrimp, lobster, giant squid (*Architeuthis dux*) and crabs. Over 50 families of fish use sound to communicate and obtain information from and about their environment, as well as for defence, protection of territory and reproduction. Unique to fish is the lateral line, a band of sensory cells running the length of their body on both sides that can pick up and amplify low-frequency sound. Fish suffer noise-induced hearing loss and damage to eggs and larvae, they abandon noisy areas, and those with swim bladders passively receive unwanted noise that is amplified through these organs.

Noise pollution also makes species communicate more loudly, thereby further increasing overall ambient noise levels in the ocean. Whale songs are longer when submarine detectors are on. If cetaceans don't 'speak' loudly enough, their voice can be masked by anthropogenic sounds. These unheard voices might be warnings, finding of prey or preparations for net-bubbling. When one species begins to speak more loudly, it will mask the voices of other species, eventually raising the volume of noise across the whole ecosystem.

Noise has adverse cumulative and synergistic effects on marine biodiversity and ecosystems, including seamounts and other habitats far from coasts and shipping lanes. Ocean acidification, one of the consequences of global warming due to excessive CO_2 emissions, can exacerbate noise pollution: it makes noise louder, especially for frequencies below about 10 kHz, as does the warming of the ocean itself, also in the lower frequency range. See also Section C (1) on anthropogenic climate change.

The effects of noise were eloquently summarized by Dr Sylvia Earle (2005): "Undersea noise pollution is like the death of a thousand cuts. Each sound in itself may not be a matter of critical concern, but taken all together, the noise from shipping, seismic surveys, and military activity is creating a totally different environment than existed even 50 years ago. That high level of noise is bound to have a hard, sweeping impact on life in the sea."

7. Shading and lighting

Shading occurs when vessels spend a long time in one position at sea. Prolonged light reduction by stationary vessels can adversely affect the benthos underneath. The effects would depend on the size and number of the stationary vessels and the duration of their stay. As far as this author is aware, there are no studies of these effects caused by stationary vessels at sea. Extrapolation from near-shore studies comparing under-bridge with bridge-free reference sites suggests that reduction in local photosynthesis, and therefore in the phyto- and zoo-plankton communities and thus in the food available to the benthic community under the shaded area, with the attendant community and ecological changes, might reasonably be expected.

The obverse of abnormal shading during the day is excessive light at night. Long-term stationary ships at sea that are lit up at night, especially during lunar dark periods, can disrupt the light-dark cycles that condition many physiological mechanisms and ecological responses. Ecologically inappropriate lighting may have adverse effects on the pelagic communities that migrate towards the surface at night and return to depth during the day, on predator-prey interactions, and on the benthic community, all of which are found in association with seamounts.

8. Washes and wakes

In general, washes and wakes must be considered in waters where the wake and wash generated are greater than the natural background wave conditions. The effect of washes and wakes on marine ecosystems and biodiversity will vary with the type of habitat and ecosystem involved and on how the wash and wake regime differs from the natural wave climate at a given habitat or ecosystem. This regime will also depend on the number, size, speed and type of vessels, including propeller and hull shape, and the transit frequency. Boat design can reduce boat wake, particularly bow design and the hull profile under water. Different types of vessel create different magnitudes of wash with different wave energy levels. Damage caused by a wake is directly related to its height: for example, a wave that is 25 cm high causes five times more damage than one of only 12.5 cm. Ship wakes may cause unusually high near-bottom velocities at depths of 5-30 m. At such velocities, the impact of a typical ship wake on bottom sediments and aquatic wildlife at these depths is comparable with or can even exceed the impact of wind waves whipped up by violent storms, and considerably exceeds the effect of local currents.

Where the local ecosystem is adjusted to low near-bottom velocities, fast ship-induced waves can become a new environmental threat at certain depths. An abrupt intensification of sediment transport processes at those depths may change the existing balance of sediment distribution. Mobilization of larger sediments can result in rapid changes to biological communities. Sedentary organisms may be relocated, crushed and damaged as the rocks and boulders on which they are attached are rolled around. Resuspension of finer sediments can create an abrasive environment that may damage soft-bodied animals and algae and prevent spores from settling. When sediments do settle out, they can potentially smother benthic organisms and cover fish eggs and spawning grounds. Aquatic plants can be physiologically impaired if their surfaces are covered with silt. Resuspension of sediments also increases the turbidity of the water and, by blocking the light that reaches the bottom, can adversely affect benthic organisms. Another potential mechanical effect of ship waves, if the bottom is shallow enough, is enhancement of vertical mixing along the ship's path. Due to the transport of nutrients from sediments and the lower water column into the euphotic layer, phytoplankton production may intensify but also promote eutrophication and HABs.

Environmental studies of washes and wakes have, to the best of the author's knowledge, so far only been conducted in shallow, confined waters. In open waters, the effect of washes and wakes compared to the natural wave processes is generally much less and is not usually a matter of concern. For seamounts in the open ocean with no nearby shores, extrapolation from the near-shore studies suggests that any environmental effects are likely to be primarily a function of the depth of the seamount summit, especially if that summit is shallower than about 40 m.

B. Activities for which the ship serves primarily as a platform

1. Archaeology

Archaeological activities relevant to this paper are usually conducted on shipwrecks. Insofar as these shipwrecks are found on or near seamounts, the environmental threats are those listed in Section A above from all ships. The nature of their effects will be similar, and their actual occurrence and extent will depend on the sensitivity of the archaeological team to the environmental threats posed by the presence of their ship over the site and the efforts made to reduce and preferably eliminate them.

As for the activity itself, defined by Dr Keith Muckelroy as "the scientific study of the material remains of man and his activities upon the sea" (quoted in Verlaan, 1989), marine archaeology, when conducted to the highest professional standards, is not likely to pose substantial threats to the marine environment, biodiversity and ecosystems of the seamount. This is because the archaeological value rests with the wreck *in situ*, unaltered by anthropogenic intervention since the vessel sank to the seafloor. Removal of any remains, even if only for further study, "without painstaking recording...of their archaeological context *in situ*, destroys the scientific value of the removed object and diminishes the value for the site as a whole for archaeologists, historians, oceanographers, and other scientists" (*Ibid*.). Hence archaeological investigations of deep-sea wrecks focus on non-invasive and non-extractive examination. Technology makes it possible to do so. Nevertheless, the noise, light and other disruption associated with the presence of researchers, either indirectly via various remotely operated vehicles (ROVs), or directly in various submersible human-occupied systems, cannot be neglected as a source of potentially adverse environmental effects. See also Section B (11), on salvage, which includes a discussion of 'treasure-hunting' at sea, which must not be confused with archaeology.

The 2001 International Convention on the Protection of the Underwater Cultural Heritage (UCH Convention) strengthens in international law the preference for *itu* preservation (Art. 2(5)), and sets out, in its Annex 36, rules for the responsible management of marine archaeology, including the marine environment. Article 3 specifically invokes the UCH Convention's consistency with and emphasizes the primacy of the LOSC, which reinforces the applicability of the marine environmental provisions of the LOSC to marine archaeological activities.

In ABNJ, LOSC Article 149 provides that objects of an archaeological and historical nature found in the Area "shall be preserved or disposed of for the benefit of mankind as a whole", which is not inconsistent with the foregoing analysis. As all activities under the LOSC must be conducted according to the rules governing the protection and preservation of the marine environment, seamounts in the high seas with archaeological attractions must also be protected from the environmental threats and effects caused by these investigations.

2. Artificial islands and fixed/floating installations

Construction and operation of such facilities ever further out in the open ocean for such purposes as marine mining (see also Section B (5)), ocean-based energy generation from, e.g., currents, nuclear, ocean thermal energy conversion (OTEC), solar, waves), mariculture, and recreation (see also Section B (10)) are likely to become more common as suitable coastal space becomes increasingly rare.

Any construction and operation of such facilities in the vicinity of, or directly over, seamounts will involve threats to marine biodiversity and ecosystems. The degree of threat and actual impacts will vary according to facility siting and design, construction methods and materials, and operational requirements, but include effects associated with shipping (see Section A above), as well as those arising from construction and operation, including many of those addressed in the present Section B (e.g., (4) dumping; (9) piracy/criminal activities; (10) recreation; (12) undersea cable- and pipeline-laying). Moreover, such facilities may interfere with migratory and species dispersal routes, species distribution, and current flow patterns.

3. Bioprospecting

There is as yet no definition of bioprospecting in international law. The CBD Secretariat has defined bioprospecting as “the process of gathering information from the biosphere on the molecular composition of genetic resources for the development of new commercial products” (quoted in Warner, 2008), which suffices for present purposes. Information from the marine part of the biosphere is the focus here, and of particular interest are the genetic resources of marine macro- and micro-organisms, the latter including archaea, bacteria, fungi and viruses.

Seamount ecosystems, with their often high levels of endemism and biodiversity, and, depending on their depth and location, their situation in areas of comparatively extreme ambient conditions (e.g., high pressure, low temperatures), are likely to be attractive sites for bioprospecting. As such, they are vulnerable to the threats and their effects on marine biodiversity and ecosystems associated with shipping activities (see Section A above). They are also vulnerable to excessive sampling by different groups interested in the same organism(s), which can result in alteration or loss of habitat, and, depending on the organism, endanger its own survival as a population or even an entire species, or that of groups and species dependent on it. Repeated visits to the same seamount site directly and proximately exposes these ecosystems to abnormal light, noise, extraneous biological matter and other disturbances. See also Section B (6) on marine scientific research, from which bioprospecting cannot easily be distinguished. The two activities are often conducted simultaneously.

4. Dumping

Dumping is distinguished from 'discharge' as defined under MARPOL, which specifically excludes dumping. 'Operational discharges' are excluded from the definition of dumping (see Section A (1). Dumping under LOSC Art.1(5) and the 1972 London Convention Art. III is defined as "any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other man-made structures" and of "vessels, aircraft, platforms or other man-made structures themselves". The 1996 London Protocol adds to the definition of dumping, "any storage of wastes or other matter in the seabed and the subsoil thereof from vessels, aircraft, platforms or other man-made structures at sea; and any abandonment or toppling at site of platforms or other man-made structures at sea, for the sole purpose of deliberate disposal" (Art. 1(4)(.1)(.3-.4).

'Wastes or other matter' that may still be dumped under the London Protocol, albeit with permit, currently includes: dredged material; sewage sludge; fish waste, or material resulting from industrial fish processing operations; inert, inorganic geological material; organic material of natural origin; bulky items primarily comprising iron, steel, concrete and similar harmless materials, for which the concern is physical impact, and limited to those circumstances where such wastes are generated at locations, such as small islands with isolated communities, having no practicable access to disposal options other than dumping; and (since 2008) storage of CO_2 under the seabed in sub-seabed geological formations (SSGFs). However, the disposal or storage of wastes or other matter directly arising from, or related to the exploration, exploitation and associated offshore processing of seabed mineral resources is not covered under the dumping treaties (see Section B (5) for threats and effects in association with marine mining).

Insofar as any of these materials, even with permit, are dumped in or near seamounts, the adverse effects will include alteration, degradation and destruction of habitat, both on the seafloor and in the overlying water column, and destruction of and injury to marine organisms, especially sessile and slow-moving ones, by, e.g., smothering, increased local sedimentation and turbidity, oxygen depletion, and pollution from dumped waste that is contaminated by substances such as those described in Section A (1) above.

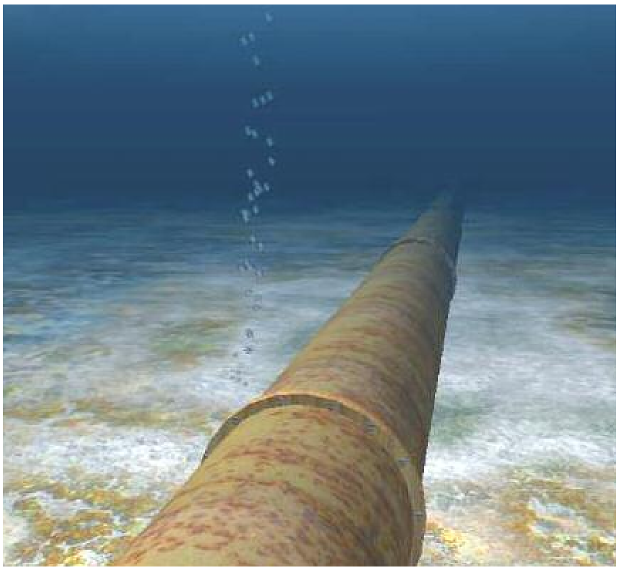
Although the dumping of radioactive wastes was banned in 1993, these have been dumped as recently as 1993, and perhaps thereafter as well – especially in the North Atlantic, the Arctic Ocean, the north Pacific, and the Sea of Japan/East Sea. Also dumped in the oceans were nuclear submarines, their reactors and warheads, contaminated cooling water from reactors, conventional and chemical munitions, nerve and mustard gas, live bombs and other explosives, and whole ships, often still carrying munitions. Military dumping sites are not known to be monitored for their release of radioactivity, or for other noxious materials, such as nerve gases. These sources of radioactive, chemical and heavy metal pollution can still constitute a threat to seamounts in the open ocean, due to transport by currents. See also Section B (7) on military activities and Section C (5) on radionucleides.

5. Marine mining

a. Minerals – fuel

i. Oil and gas

Seamounts themselves and their immediate surroundings are unlikely to be of interest for oil and gas prospecting and exploitation because of the very different geological conditions governing the formation of seamounts on the one hand and oil and gas deposits on the other. However, as oil and gas activities move ever further offshore and ever deeper into the sea, some seamounts may be located near enough to or directly under the shipping route to and from areas with such potential that these activities could adversely affect seamount ecosystems. The shipping threats and their effects (Section A, above) will be relevant here, as will many of the threats and



Oil pipeline.
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effects in the present Section B (e.g., (4) dumping; (9) piracy/criminal activities; (10) recreation; (12) undersea cable- and pipeline-laying).

Prospecting and exploitation involve such environmental threats and their effects as: noise (from air guns, sonar, machinery, drilling); pollution from drilling muds and drill cutting piles, which can be contaminated by hydrocarbons and chemicals, including drilling fluids; leaks and spills of oil and gas; and destruction of benthic habitat and sessile organisms. If installations (e.g., rigs, platforms) are constructed or brought in and placed, the effects associated with those activities must be considered (see also Section B (2) above on the construction of offshore installations and artificial islands).

ii. Methane hydrates

This potential fuel source is composed of a molecule of methane held in a lattice of ice, i.e., frozen molecules of water. In the ocean it is found at up to 2,000 m depth under polar seas and on continental slopes. As with oil and gas deposits, methane hydrates are unlikely to be found on or near seamounts, but, as also with oil and gas deposits, seamounts may be located in the path of their eventual exploitation, with similar potentially adverse environmental consequences.

However, should methane extraction take place on a commercial scale, the following threats specific to this activity that are relevant to seamount biodiversity and ecosystems must be considered. These hydrates are important to the maintenance of slope stability. Their removal could trigger massive underwater slides of sediments down into the deep sea, generating extreme and prolonged turbidity, smothering the benthos and destroying habitats, communities and ecosystems, as well as releasing the gas into the sea where its effects are not well studied; as methane is generally associated with anaerobic or hypoxic processes, it is unlikely to be benign in waters that are normally oxic. An example is provided by the Storegga Slides off Norway, of which the latest – so far – occurred around 6100 BCE, when a 290-km stretch of coast slumped into the sea and some 3,500 km^3 of material cascaded into the deep sea.

Furthermore, the released gas will eventually enter the atmosphere, where, as it is 20 times more potent a GHG than CO_2, it will exacerbate global warming, with the attendant deleterious effects thereof on the marine environment and thus also on seamount ecosystems (see also Section C (1) on anthropogenic climate change). A slope collapse may also generate a tsunami, but the effects of the latter are unlikely to be felt on seamounts unless they are very shallow and close to a coast. Even during controlled drilling, the environmental effects of any accidental excessive release of gas to the water column and the atmosphere must be considered. Finally, methane hydrates do not occur in discrete formations – they are dispersed throughout the sediments, such that mining them will require large-scale removal of sediments, entailing concomitant destruction and disruption of their fauna and associated ecosystems, with all the environmental consequences thereof in addition to those deriving from the creation of additional turbidity and sediment suspension. Their presence may also present a risk, especially of explosive gas release, to oil and gas operations, with all the attendant environmental consequences.

b. Minerals – non-fuel

i. Ferro-manganese nodules and crusts

These deposits are rich in economically important metals, including, in particular, Mn, Ni, Cu and Co in both, and Pt in crusts. The deposits of resource interest are not associated with hydrothermal vent processes or ecosystems. Depth-wise, the most economically attractive crusts and nodules are found, respectively, on hard, sediment-free surfaces of seamounts at about 1,000-2,500 m and in sediments at about 4,000-5,500 m. Both deposits are sources of hard surfaces in the deep sea, with their own communities of organisms dependent on hard surfaces – i.e., they cannot live on sediments. Mining entails removal of these hard surfaces in the case of both deposits, and, in the case of nodules, massive disruption of the associated sediments as well.

Consequently, in addition to the destruction of the communities themselves, crust and nodule mining also destroys their habitat. Nodules and crusts of interest here form extremely slowly, at most, for nodules, a few mm every million years, while crusts form even more slowly. These are not easily renewable substrata – or resources. In the case of the communities dependent on the nodules themselves, it is unlikely that recolonization can occur at all, given that the requisite hard surface represented by nodules has been removed. In the case of crusts, the new surface exposed after crust removal (and with current technology, the top part of the underlying substratum will be removed as well), even though it is hard, may not be suitable for recolonization by crust-associated organisms. The only deep-sea seamount crust colonization experiment carried out *in situ* known to (and conducted by) this author (Verlaan, 1992) suggests that some species may require crust for recruitment.

Recolonization of the sediment-associated communities may occur, but it is not known how long it will take. It is known that deep-sea colonization processes are extremely slow. Furthermore, given the lack of knowledge on the degree of endemism in the sediment communities associated with nodule deposits, it is unknown whether the same communities would – or could – in fact regenerate in areas where nodules have been removed. Finally, it is not only sessile and less mobile organisms that are potentially affected by nodule and crust mining. The effects of the removal of these deposits on associated demersal and other mobile organisms are unknown: they may have been able to escape destruction by the mining operation itself, but their requirements for these deposits *in situ* (e.g., to attach eggs, to provide refuge for juveniles) will not be met.

The potential adverse environmental effects are unlikely to remain confined to the mine site. In both cases, but particularly with sediment-hosted nodules, mining can generate massive sediment plumes in the water column that can smother and suffocate sessile and less mobile benthic and demersal organisms at and downstream of the mine site, as well as increasing the turbidity of the water, which interferes with processes dependent on visibility, such as bioluminescence. It is unknown whether resuspension of metal-rich sediments will also render the ambient water column toxic because of the enhanced concentration of potentially toxic metals in the water, but this possibility should not be overlooked. Sediment plumes ejected near the surface could interfere with light penetration and, hence, photosynthesis, and disrupt the local food web. It is also possible that the nutrients brought up from deeper water with the sediments and ejected near the surface may cause productivity blooms which the local environment cannot assimilate, causing eutrophication, HABs, hypoxia and ecosystem disruption. Finally, the environmental threats and their effects associated with shipping (see Section A above), and also to some extent with oil and gas recovery (see Section B (5) (a) (i) above) are applicable here. Because of their seamount location, crust mining presents a particularly important threat to seamount ecosystems.

ii. Polymetallic sulphides

These deposits form by hydrothermal processes and are found associated with hydrothermal vents and their ecosystems in volcanically active submarine areas. They are rich in economically important metals, including, in particular, Au, Ag, Cu and Zn. Mining is likely to occur, at least initially, at inactive vent sites, which pose fewer technological challenges in terms of dealing with the extremely hot, corrosive fluids emitted from active vents. The profuse communities (tube worms, clams, etc.) so characteristic of active vents vanish when the vents become inactive; hence these communities are unlikely to be at risk from mining activities unless the inactive vent mining sites are near enough to active sites to affect the latter, e.g., by sedimentation or shipping-related threats.

The inactive vent sites have their own communities, about which little is known, including how dependent they are on the metal-rich substratum of the vents themselves and of the surrounding sediments. Mining will remove the former and disrupt the latter, with environmental effects that are unknown but which can reasonably be surmised. Based on knowledge of deep-sea ecology in general, and of ferromanganese nodule and crust work in particular, the effects are likely to take a very long time to dissipate where the sediment-associated communities are concerned, and not at all for the communities actually living in or on or otherwise dependent on the mined polymetallic sulphide deposit itself, as that will have been removed.

Habitat degradation and destruction, the latter irremediable in the case of the deposit itself, are likely to be the result of polymetallic sulphide mining. Furthermore, it is unknown whether and to what extent the organisms associated with inactive vent sites are endemic. Adverse environmental effects of mining on seamount ecology and biodiversity, if any, will be a function of the proximity of seamount communities to the mine sites and the scale of the mining operation, and are likely to be similar to those discussed above (Section 5 (a) (i) and (b) (i) above for Fe-Mn deposits and oil and gas). Again, sediment plumes, if uncontrolled, are likely to be a major threat.

iii. Phosphorites, limestone, sand and gravel

Depending on their location, depth and geological history, seamounts can be a source of supply for these mineral resources. Each resource is associated with a particular habitat and a distinctive community. Mining of the resource will destroy the immediate habitat and its associated community of sessile and less mobile organisms, as well as making it unavailable to demersal and other mobile organisms. The surrounding unmined habitat and its communities will be degraded by environmental effects similar to those described above (see Section 5 (a) (i) oil and gas, (b) (i) for Fe-Mn deposits, and b (ii) for polymetallic sulphides).

6. Marine scientific research

Marine scientific research (MSR) is as yet undefined in international law. The LOSC devotes all of Part XII to MSR, and addresses it elsewhere in the body of the text as well. In practice, MSR can overlap with surveys and mapping, which are essential for a variety of ocean activities, including fuel and non-fuel mineral development and exploitation, cable and pipeline laying, installation of equipment and structures offshore, military operations, exploration for resources, and conducting MSR itself. The LOSC also recognizes the existence of a distinction between MSR and other forms of information-gathering at sea, as it refers to hydrographic surveys, as well as simply to 'surveys' and to 'research', albeit much less frequently than it refers to MSR. These differences are important – particularly in terms of the conditions governing the right to conduct the activity, which vary according to whether it is (or can be argued to be) MSR or not – but they will not be addressed further here.

For the purposes of this paper, MSR is construed as encompassing all activities designed to obtain information about the ocean in the broadest possible sense. These will include hydrography, mapping and surveying, regardless of whether the activity has a military or industrial/commercial objective. Bioprospecting (see also Section B (3) above) can fall into the MSR category as defined here as well. It is the potential for environmental threats posed by this information-gathering to seamount biodiversity and ecology that is examined here.

Information-gathering can be either passive, i.e., as minimally intrusive as possible, or active. It is the active form that is likely to have adverse environmental effects. It includes drilling, sampling (e.g., cores, dredges, trawls and nets, all of various sizes and designs), acoustic emissions, such as sonars, at various frequencies, as well as seismic air guns, explosions, deployment of light, and *in situ* experiments. Industrial/commercial and military information-gathering activities are likely to be more environmentally problematic because they are usually much more intrusive in terms of duration, intensity and scale than scientific ones. In particular the use of sound (sonar and seismic) by industry and the military for their information-gathering is a grave cause of concern (see also Section A (6) above on noise).

Information-gathering by scientists is usually done in a context that involves hypothesis-testing, whereby it is usually necessary to leave the environment about which and wherein the hypothesis is being tested as undisturbed as possible for the observations made to be accurate and the conclusions drawn to be meaningful. This context generally entails scientific intrusions on scales that are unlikely to have environmentally adverse effects. However, recent years have seen the development of information-gathering by scientists that must – by the very nature of the underlying hypothesis to be tested – intentionally perturb or manipulate the marine environment on scales that not only will have environmental effects but effects that cannot be guaranteed to be benign.

One such experiment involved periodic underwater release, over several years, of low-frequency acoustic signals that could be received at distances of 18,000 km from their source, and thus across entire ocean basins, to investigate whether global ocean temperatures were increasing. An increasing number of experiments (a dozen at the time of writing) are seeding up to (so far) 100 km^2 in the equatorial and sub-Arctic Pacific and the Southern Ocean with iron, an essential micronutrient, in order to determine whether the low level of phytoplankton productivity observed in these regions is related to a possible insufficient availability of iron (see also Section B (8) on ocean-based climate-change mitigation). Placement on the seafloor of a network of ocean observatories linked by cables to the land is ongoing in the Atlantic and the Pacific; the European Seafloor Observatory Network (ESONET) is projecting some 5,000 km of cables (see also Section B (12) (a) on cables).

In conclusion, the extent to which this information-gathering is likely to cause adverse environmental effects on seamount biodiversity and ecosystems will depend on the spatial and temporal scale of the activity, and its nature and intensity. The environmental effects discussed elsewhere in this section in relation to specific underwater activities, and the general shipping-related environmental threats and their effects set out in Section A, cover the scope of the threats and effects that may be expected from MSR/information-gathering.

7. Military activities

The environmental effects of military activities at sea are difficult to assess; national security arguments tend to trump all other considerations, including environmental ones. The military is not necessarily subject to the same national and international marine environmental rules applicable to marine activities conducted by other segments of society. In many cases the military may be formally exempted from such rules by national and international law. It is not unlikely that military activities at sea will pose the threats and cause the effects outlined in Section A above, as well as in Section B (2) on construction of artificial islands and fixed/floating installations, Section B (4) on dumping and Section B (6) on MSR/information-gathering. In addition to munitions disposal (see Section B (4) above under dumping), military exercises and weapons testing, which often include bombing and shelling of islands, deleterious effects also involve concentrated, albeit intermittent, sources of extreme noise (see Section A (6) above) and more intense inputs of the environmental stresses already described above.

A potential threat to seamounts specifically is the possible prolonged presence of submarines, which find seamounts to be convenient locations to conceal themselves. Noise is probably not the principal threat here because submarines place a premium on silent operations and movement. Collisions with marine mammals, grounding and IAS (see Section A (3-5) above) are possible threats, as well as operational or accidental discharges of the substances listed in Section A (1), whose effects might be exacerbated by the proximity of the submarine to the seamount should any of these threats materialize from that source.

8. Ocean-based climate-change mitigation

Ocean-based climate-change mitigation activities fall into one of two broad categories:

a) Lowering atmospheric CO_2 by accelerating its removal from and delaying its return to the atmosphere;

b) Lessening incoming solar light and heat by deflecting it directly or by increasing the planet's albedo (reflectivity), thereby offsetting warming caused by rising CO_2 (and other GHG emissions).

In category (a), atmospheric CO_2 is captured and placed in the oceans for long-term 'storage' away from the atmosphere. This category includes:

i) capture of CO_2 from point sources of emission, and its transfer (by ship or pipeline) to and storage (CCS) in SSGFs. These SSGFs include depleted offshore oil and gas fields and sub-seabed saline aquifers; they exist worldwide and are said to be able to store quantities of CO_2 equivalent to some decades of global emissions. At the time of writing, CCS in SSGFs has begun on a modest scale off Norway.

ii) capture of atmospheric CO_2 by ocean fertilization. This involves increasing phytoplankton productivity through targeted specific nutrient addition (e.g., iron, nitrate, phosphate, urea) or general nutrient enhancement (by artificially inducing upwelling of nutrient-rich deep ocean water) to surface seawater, thereby increasing the concomitant transport of fixed carbon to depths from which, it is hoped, this carbon would be unlikely to re-enter the atmosphere as CO_2 for a century. See also above under Section B (6) on MSR)

In category (b), the effect of sunlight is reduced by increasing the albedo and cover of marine clouds through injection from ships of aerosols composed of seawater droplets and dissolved salts into the atmosphere at 300 m altitude. As the droplets evaporate, their salt crystals reflect sunlight and become condensation nuclei for new droplets, thereby increasing marine cloud cover and reflecting even more sunlight. To the best of this author's knowledge, this planetary shading option has not yet been tried at sea. Furthermore, ocean fertilization and planetary shading may be mutually incompatible, as the latter will reduce the light needed for photosynthesis in the former, without which less carbon will be fixed from CO_2 and less carbon will therefore be available to sink to depth (see also Section A (7) above on shading).

Basic technical feasibility, if not actual effectiveness, has been demonstrated for the methods proposed. Economic feasibility is not addressed here, other than to offer the view that it is unlikely to be an issue, because financing will be(come) available if the motivation (which need not be environmental) to engage in one or more of these activities is great enough.

If these activities really are able to effectively mitigate anthropogenic climate change, they must be conducted on long temporal scales (several decades) and on huge spatial scales (multiple large sites in all oceans). Should this indeed occur, the threats to and effects on marine biodiversity, marine ecosystems and marine environment as a whole are likely to be sufficiently adverse that it would be futile to single out seamounts as subjects of particular environmental concern. A highly qualified exception to this dismal scenario might perhaps be made, at least initially, for CCS in SSGFs. But this must be properly carried out; i.e., no escape of CO_2 from the SSGFs must occur, because if it does, ocean acidification, already a problem in the upper water column (see also Section C (1)) will be exacerbated at depth.

Consequently, for the purposes of this paper, the principal immediate threat to seamount biodiversity and ecosystems from ocean-based climate-change mitigation activities derives from their testing in the vicinity of seamounts, where proximity and/or the effect of local and regional circulation and productivity patterns operate to concentrate their effects on these seamounts. The effects will include all the generic shipping-based effects set out above in Section A, and the effects associated with artificial islands and floating installations, dumping and MSR in Section B (2), (4) and (6) respectively.

Effects specifically associated with ocean fertilization are not as yet fully characterized, but enough is already known about the processes involved to predict that these will include changes in species and community composition, as well as in the productivity of the phyto- and zoo-plankton, in the benthic, demersal and pelagic communities, and the food web as a whole. Immobile benthic communities, which are ultimately dependent on surface productivity, are likely to be especially vulnerable to these changes. Furthermore, ocean acidification (see also Section C (1) on anthropogenic climate change) may be exacerbated by the increased dissolution of CO_2, and hypoxic or anoxic zones may develop as a result of increased decomposition of organic matter in the water column where circulation is such that oxygen is either not or only inadequately replenished. In summary, the effects of ocean fertilization on seamount communities are unlikely to be benign.

9. Piracy/criminal activities

Arts. 100-107 of the LOSC deal with piracy, underlining its importance as an issue of global concern. The definition of piracy in LOSC Art. 101 is complex, but essentially it requires the use of a ship or aircraft to commit any illegal act of violence or detention, or any act of depredation directed against another ship or aircraft or against persons or property aboard same, in ABNJ. The Convention for the Suppression of Unlawful Acts Against the Safety of Maritime Navigation, 1988 (SUA Convention) and its two Protocols, promulgated under the auspices of IMO, elaborate on the piracy provisions of the LOSC, and, with particular relevance to the purposes of this paper, requires that the measures taken by a State against these offences are environmentally sound.

With regard to threats posed to seamount ecology and biodiversity by piracy and other criminal activities at sea, the threats and effects discussed in Section A above are implicated to a greater or lesser extent, depending in particular on the fate of the pirate vessel and the victim vessel, especially if these vessels are damaged or wrecked near a seamount. Since pirates are ranging further and further out to sea, up to hundreds of kilometres from shore, the remote location of seamounts is not likely to be substantially shielded from their attentions, especially if the seamount itself or waters nearby attract ships for legitimate activities such as those enumerated elsewhere in this section.

10. Recreation

Ocean-based recreation is a major global growth sector in which the remoteness, inaccessibility and ecological fragility and uniqueness of sites are a particularly potent inducement to visit. Seamounts, with their enhanced biodiversity, are likely to be attractive marine recreational sites, offering a variety of opportunities, depending on depth, for surface and sub-surface marine tourism by cruise ships and submersibles, respectively, as well as for swimming, snorkeling and diving, yachting (motor and sail) and sports fishing (this final item is addressed in Chapter 2).

All the threats and their effects covered in Section A are likely to be involved to a greater or lesser extent if seamounts become a recreational site, as are, in particular, the threats and effects under Section B (2) construction of artificial islands and fixed/floating installations, (4) dumping and (9) piracy. Tourist submersibles can introduce light pollution at depth, as can cruise ships at night in the upper water column if they remain on station. Both are a source of proximate noise, as are the support vessels for swimming, snorkeling, diving and sports fishing. Other adverse effects include removal of shells, corals and other marine organisms as souvenirs, as well as the potential for disturbance of seamount sites important for scientific research, monitoring, biodiversity conservation, and their historical and archaeological value.

11. Salvage

Salvage is defined in the 1989 International Convention on Salvage as "any act or activity undertaken to assist a vessel or any other property in danger in navigable waters or in any other waters whatsoever" (Art.1(a)). The concept of salvage is designed to promote the voluntary rescue of goods and vessels imperiled at sea. The Salvage Convention provides for an enhanced salvage award that takes into account the skill and efforts of the salvors in preventing or minimizing damage to the environment. It also provides for 'special compensation' to be paid to salvors who have failed to earn a reward in the normal way (i.e., by salving the ship and cargo) but who have prevented or minimized damage to the environment. Damage to the environment is defined as "substantial physical damage to human health or to marine life or resources in coastal or inland waters or areas adjacent thereto, caused by pollution, contamination, fire, explosion or similar major incidents"(Art.1(d)). However, if the salvor fails to prevent or minimize environmental damage, special compensation may be denied or reduced. Therefore, although the salvage process can entail risks to the environment, the salvage reward system provides a strong incentive to minimize environmental damage.

For ships or goods imperiled near or over seamounts, salvage operations are most likely to be conducted by specialized salvage tugs or vessels, which may also include diving facilities. Rapid action is especially necessary offshore in exposed waters because sea state and weather conditions can deteriorate quickly, such that salving is not possible until conditions improve, by which time the vessel, its cargo, and the environment may all be beyond help. Under such circumstances, saving the vessel's cargo and equipment is often a higher priority than saving the vessel herself. The cargo may pose an environmental hazard or include expensive items and materials; the equipment may include valuable machinery. In this case, salvors will focus on rapidly removing the goods of interest, and although they may deliberately destroy the hull to do so most efficiently, it is in their financial interest to do so in an environmentally responsible manner. Although it will never be environmentally beneficial to seamount ecosystems and biodiversity to have a vessel come to grief nearby or on it, modern salvage operations are not likely to exacerbate the environmental consequences unduly, and they may even mitigate or prevent them.

This sanguine assessment is unlikely to be applicable to marine treasure-hunting. Often confused with both marine archaeology (see also Section B (1) above) and salvage – a confusion which is not necessarily scrupulously cleared up by treasure-hunters – marine treasure-hunting is driven by profit motives to retrieve items with market value from wrecks at minimum cost to the treasure-hunters. Environmental concerns are not usually uppermost in their calculations. Seamount ecosystems bearing wrecks of interest to treasure-hunters are therefore likely to be more at risk from their attentions than from those of salvors or marine archaeologists. For both salvage and treasure-hunting, however, the threats and effects described above in Section A remain applicable; see in particular Section A (4) on grounding and shipwreck.

12. Undersea cable- and pipeline-laying

a. Cables

Submarine cable-laying began in 1858, when the first undersea cable linked Britain and Newfoundland via the seafloor of the North Atlantic. Some 100,000 km of submarine cable are now being laid every year. Most international telephone and internet communications travel via submarine cables. Although most cables are still being laid in the North Atlantic, they are now found in all the oceans, and cable-laying is increasing in particular in the Indian and Pacific Oceans. As cables are best placed on smooth flat seafloor, the likelihood of their placement directly on topographically complex seamounts, and thus of their ability to directly affect seamount biodiversity and ecosystems, is low.

Insofar as cables are placed on the seafloor near seamounts, the process of their placement, maintenance and repair may adversely affect adjacent seamount ecosystems, depending on their proximity to the cable-related activities. Because bottom-trawling is the main threat to submarine cables, they are generally buried 1-3 m below the seabed where the seabed is at depths still accessible to bottom trawls (1,500-2,000 m water depth). Burial involves digging a narrow trench (cables, when armoured, are about 50 mm in diameter), inserting the cable and covering it up. In addition to the effects of the presence of the ship as outlined in Section A above, and the physical destruction of the seafloor itself and any organisms that were unable to escape the trenching, the other principal environmental effect of this process is the creation of sediment plumes. These can spread far from the site, if currents and seafloor conditions are conducive thereto, with the associated well-known smothering and turbidity effects described elsewhere in this paper (e.g., Section B (5) on marine mining).

In deep water where bottom-trawling is not a risk and the seabed is not rough, cables are not armoured (and are thinner, ~17-21 mm in diameter) and are placed directly on the seabed. Under these circumstances the environmental effects are likely to be minimal.

The increasing use of seabed ocean observatories in MSR projects, which by their very purpose may require their placement in environmentally sensitive areas, such as seamounts, necessitates cabling to connect the observatories to their land-based stations, and should be considered an emerging potential threat.

b. Pipelines

Pipelines are so far only used for transporting oil and gas, although CO_2 could join them in the future (see also Section B (8) above on ocean-based climate-change mitigation activities). Pipelines are much bigger (up to 900 mm in diameter) and require more construction work for their placement than cables, as well as more environmentally intrusive maintenance and repair. They are not often buried, but more usually placed directly on the seafloor, where again, as with cables, smooth topography is preferred. Pipelines can also leak or break, releasing their contents to the marine environment, with effects that will depend on the quantity, type of substance, and local temperature and pressure, as well as the nature and proximity of marine organisms, communities and ecosystems. As with cables, pipelines are unlikely to be placed directly on seamounts, but they may prove to be a threat to seamount ecosystems if they are placed on the seafloor nearby.

C. Threats from activities not involving ships

This final section briefly highlights some of the most important overarching anthropogenic threats to which seamount biodiversity and ecosystems are all vulnerable. They constitute a set of chronic, growing stresses that must be considered in assessing the possible effects of the specific additional threats to seamount ecosystems and biodiversity described in Sections A and B.

1. Anthropogenic climate change

The oceans and the atmosphere are closely linked; between them they account for the bulk of heat and gas circulation on the planet. Anthropogenic climate change is caused by the excessive accumulation of GHG in and hence the excessive warming of the atmosphere by activities such as fossil fuel burning, deforestation (especially trees and mangroves) and cattle production. This warming will alter the pattern of heat and gas distribution on the planet. Changes in precipitation (rain and snow), ocean circulation (e.g., currents, up- and down-welling), temperature, salinity, storm patterns and paths, and sea level can be expected. Adverse effects on marine ecosystems and biodiversity include ocean acidification, ocean warming, ocean oxygen content reduction, eutrophication, HABs, turbidity, noise amplification and methane leakage. These all contribute to marine habitat degradation. Migration routes, nutrient supplies, food web structures, species and community composition could change such that entire groups of organisms and ecosystems might disappear. The joint, several and cumulative effects of warm, acidic, hypoxic, cloudy, noisy, methane-rich waters on marine ecosystems, benthic and pelagic communities, and the physiology, behaviour and reproduction of biota unaccustomed to such stressful conditions are likely, at best, to reduce their resilience to and the potential for them to recover from or adjust to the effects of the threats derived from activities such as those outlined in Sections A and B above.

From this sad litany of adverse effects of anthropogenic climate change, ocean warming and ocean acidification may be singled out as likely to have the most immediately evident effects on seamount ecosystems and biodiversity. Many marine organisms live at temperatures near their physiological maximum tolerance, or their distribution and functioning are conditioned by temperature; even an apparently minor increase in the ambient temperature of their waters ('thermal shock') can have disproportionately large negative effects on them. Thermal shock may also provide opportunities for thermophilic IAS to colonize areas whose keystone native species (e.g., gorgonian corals for seamounts) are weakened by increased temperatures.

Carbonic acid forms when CO_2 dissolves in seawater, which lowers the pH. Under normal circumstances, this acid is buffered with carbonate and bicarbonate. However, the excess anthropogenic production of CO_2 is causing it to enter the ocean at a rate which is greater than the ability of the ocean to neutralize it. The oceans are naturally alkaline, with a pH of approximately 8.2, which can vary by up to 0.3 points depending on season and location. At present the pH of the oceans is down by 0.1 points, and is predicted to drop – and thus increase acidity – by at least a further 0.4 units, which exceeds the greatest natural variation in pH observed so far. As with temperature, most marine organisms can tolerate pH changes within only a narrow band.

Ocean acidification will adversely affect the wide variety of organisms (including phytoplankton, crustaceans, molluscs, corals, sponges and echinoderms) that need calcium carbonate for their skeletons, shells and other structures essential to their survival. Not only will the increasing acidity of ocean waters make it more difficult for these organisms to build them, these structures are also likely to disintegrate, as calcium carbonate dissolves under acidic conditions. Entire ecosystems that depend on a calcium carbonate substratum can be placed at risk. Living in increasingly acid waters is not healthy for non-calcifying organisms either; in fish, squid and shrimp, for example, respiratory processes can be impaired.

Finally, and ironically, recent research indicates that lower pH may hamper the ability of phytoplankton to photosynthesize, by reducing the bioavailability of Fe, an essential nutrient present in limited amounts in large parts of the open ocean (see also Section B (8) above, on ocean-based climate-change mitigation). Initial research indicates that increasing acidity (lower pH) is likely to affect the speciation, and hence the bioavailability, as well as the potential toxicity, of other essential trace metals (see also Section A (1) (g) above on heavy metals). As pointed out in Section A (6) above, low pH also amplifies noise in the sea.

2. Land-based activities

Land-based activities (including GHG emissions) constitute by far the most important (at least 80%) sources of marine pollution. Land-based sources (LBS) of pollution are the principal threat to the marine environment as a whole. Once in the sea most pollutants, through currents and gravity, eventually find their way to the deep-seafloor, with the potential to damage seamount ecosystems and biodiversity en route and on arrival. Despite the attention given to shipping in this paper, because of its seamount focus, shipping only represents ~10% of all sources of marine pollution. There is certainly room for improvement with shipping, but the elephant in that particular room is LBS, for which no land-based, global, legally binding treaty exists. The only legally binding global treaty addressing LBS is the LOSC.

Marine debris or litter, of which again the bulk (80%) is derived from LBS, represents the major threat from LBS to seamounts; its effects are discussed in the following section.

3. Marine debris or litter

Marine debris, also known as marine litter, is anthropogenic waste that has deliberately or accidentally entered the ocean. Oceanic debris is the focus of this section, as it is most relevant to seamount ecosystems. About 20% of marine debris is derived from marine activities; the rest comes from LBS. Plastics and other synthetic materials are the most common components – some 60-80% – of marine debris, and they also cause the most problems for marine organisms, especially marine mammals, seabirds and sea turtles. As pointed out in Section A (1) (f) above on garbage, the disposal of plastic at sea from ships is prohibited under MARPOL Annex V. The need for such a prohibition – and for its extension to LBS of plastic, for which it is the principal source, is evident when its adverse effects on the marine environment, biodiversity and ecosystems are considered.

Plastic degrades very slowly and can float for years. It accumulates in open-ocean oceanographic features such as convergence zones, gyres and eddies, as well as fishing grounds, which are also biologically diverse areas; it also concentrates along shipping lanes. The mass of plastic in the oceans may be as high as one hundred million metric tons. The Great Pacific Garbage Patch in the north Pacific gyre has a very high level of plastic particulates suspended in the upper water column. In samples taken in 1999, the mass of plastic exceeded that of zooplankton by a factor of six. It has been estimated that over 13,000 pieces of plastic litter are floating on every square kilometre of ocean surface.

Plastic provides vectors for the spread of IAS that are then transported to new areas via ballast

Plastic pollution on a beach. © Maleen/Marine Photobank

water (see also Section A (1) (b) above on bilge water and ballast water). As they weather, plastics break up into ever smaller pieces down to the size of sand grains. These minute particles are found in sediments and in suspension in seawater, where they resemble edible plankton, leading filter feeders and other organisms to consume them, by which they enter the ocean food chain. Their ingestion can concentrate any plastic-associated toxicants and/or adversely affect the consumers themselves. Plastics adsorb and concentrate POPs (e.g., DDT, PCBs) and PAHs.

Nurdles – also known as mermaids' tears or micro-plastics – are plastic pellets typically under 5 mm in diameter and are a major component of marine debris. They form, *inter alia*, by the physical weathering of larger plastic debris. Nurdles strongly resemble fish eggs, a food source for many organisms. The existence of micro-plastics and their potential impact on the marine environment is receiving increasing attention as evidence of their adverse environmental effects grows. There is increasing evidence that such particles are ingested by marine organisms, with the potential for: physical disruption and abrasion; toxicity of chemicals in the plastic; and toxicity of adsorbed POPs. The IMO/FAO/UNESCO-IOC/ WMO/WHO/IAEA/UN/ UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) at their 36th meeting agreed to further explore the scope of this issue through an expert workshop, focused on the occurrence and potential impact of micro-plastics, both due to their intrinsic properties (size, shape, composition) but especially as a vector for contaminants.

Fish, marine mammals, sea turtles and seabirds can mistake plastics for food. Plastic bags in particular resemble jellyfish and squid, which are major food items for these groups. Ingestion of plastic eventually kills them by causing internal injuries if the plastic is sharp, or by starvation through restricting the movement of food, or by filling the stomach and tricking the animal into thinking it is full. Sub-lethal effects include malnutrition, which can affect reproductive fitness and long-term survival of the population. They can also become trapped in, among others, plastic ropes, nets, bags, bait box bands, 'six-pack' and other rings used to hold cans together, where they will soon die from strangulation, suffocation or starvation, or by being eaten by predators taking advantage of their inability to escape.

Some 70% of marine debris will eventually sink to the seafloor, where it is regularly observed in benthic surveys at all depths. Plastic is also increasingly found on the seabed, at all depths, often in the form of plastic bags. Here they form a barrier to the movement of benthic organisms, nutrients and gases in and out of the seafloor/water column interface, and, where present, sediments. They can also cover hard and soft substrata and make them unsuitable for settlement, by for example sessile filter feeders, and for foraging by deposit feeders. See also Section A (1) (c, f) on cargo and garbage, and Chapter 2 on fisheries threats.

4. Overflight

Aircraft emissions can directly and indirectly pollute marine ABNJ and harm marine ecosystems through their contribution to global climate change. Dumping of certain wastes is still allowed from aircraft and this can place seamount ecosystems at risk if done over their location (see Section B (4) above on dumping for associated threats and effects). Noise from low-altitude flights can have harmful effects on seamount-associated species and their habitats (see also Section A (6) on noise). Increasing global air traffic heightens the risk of pollution and contamination from plane wrecks. (See also Section A (1), (3-5); although focused on shipping, the threats from and effects of the substances and activities described therein remain applicable even when the vector is an aircraft rather than a vessel.)

5. Radionucleides

These substances have very long half-lives and can be carcinogenic and mutagenic. Plutonium-239, used in reactor fuel and atomic weapons, has a half-life of some 24,000 years and is the most toxic. Cesium and strontium are also found. Nuclear weapons-testing has been the largest source of radionucleides to the sea, mostly through fallout from the atmosphere. Other sources include operational discharges from nuclear power facilities and reprocessing plants, remobilization of contaminated sediments, and radioactive waste dumping. Long-distance transport by currents has placed radionucleides everywhere in the marine environment. They can adsorb on particles that settle on the seabed and accumulate in the sediments there, which can become 50 times as radioactive as the overlying water column, with particularly adverse effects on benthic species. (See also Section B (4) above on dumping.)

A number of phytoplankton species can concentrate radionucleides to levels that can exceed those in the water column up to 200,000 times. In both cases they can enter the food chain. Radionucleide contamination has been detected in the tissues of marine mammals, seaweed, oysters and mussels. In addition to its deleterious effects on the viability of the contaminated organism, radionucleides can cause genetic damage and thus also affect later generations.

III. KNOWLEDGE GAPS

It is not fully appreciated how much knowledge is already available about the effects of human activities on marine ecosystems and marine biodiversity, including those of seamounts. Neither should the extent of our knowledge be underestimated, especially when assessing the threats, and their effects, to which human activities subject them. The preceding discussions and the list of references in Section VI represent only an illustrative sampling of this knowledge, limited in this paper by space, time and scoping constraints. That knowledge already suffices to reasonably conclude that human activities are likely to have adverse effects on seamounts and their associated ecosystems and biodiversity. Although it is not certain when and to what extent these activities will have these adverse effects, absence of certainty does not imply absence of knowledge. There will always be so-called 'scientific uncertainty', and rightly so, because knowledge can – and should – always be tested, improved and augmented. Nevertheless, for the purposes of this paper's focus on anthropogenic threats and their effects, and in the context of contributing to the development of a robust ecosystem-based management plan for seamounts, it is suggested that more research on seamounts and their associated ecosystems and biodiversity *per se* is not, in this instance, the first priority.

The existence of uncertainty and risk in other sectors is not treated as a reason for not developing responsible actions accordingly. Indeed the opposite is more usually the case, of which the insurance and re-insurance sectors and, in the shipping sector specifically, P&I clubs, are well-known examples. Uncertainty is an event with unknown probability. Risk has been defined as statistical uncertainty, that is, an event with a known probability. Most environmental problems suffer from both. At present, and despite the growing use of the precautionary principle, the inability to characterize risk and uncertainty in the environmental context has hampered efforts to protect the environment. Obtaining more knowledge of seamount ecosystems and biodiversity will not remedy this situation.

The priority knowledge gap in this context is the need for a robust mechanism to improve the determination and quantification of uncertainty and risk attendant on activities in or affecting the marine environment, such that commercially and environmentally responsible actions to address the threats of these activities to marine biodiversity and ecosystems can be developed. An open-ocean seamount ecosystem would provide a promising initial framework within which to design and test such a mechanism (see also Part IV).

IV. ANALYTICAL SUMMARY

The threats set out in Part II to seamount biodiversity and ecosystems fall into one or more of the following four overarching categories:

1. Pollution;
2. Habitat destruction, degradation and fragmentation;
3. Overexploitation; and
4. IAS.

As it does with the concepts of ecosystems and biodiversity (see Part I D above), international law provides definitions of or conceptual approaches to these overarching threats that are helpful in assessing the potential of the activities listed in Part II above to harm seamount biodiversity and ecosystems.

The definition of pollution in the LOSC is particularly useful in that it applies to the marine environment as a whole, including ABNJ, and is both comprehensive and precautionary: "[T]he introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of seawater and reduction of amenities" (Part I, Art. 1 1. (4)). The LOSC usefully distinguishes between pollution and the other three overarching threats, but does not define any of the latter.

Nevertheless, Art. 196 of the LOSC brings the use of technologies and the intentional or accidental introduction of IAS (i.e., 'alien or new species') within the concept of marine pollution, thus complementing LOSC Art. 1 (4). Note the rather prescient inclusion of 'new species', which may become particularly relevant as genetic engineering of organisms gathers momentum. The inclusion of 'use of technologies' covers activities designed for climate-change mitigation, such as the stimulation of artificial upwelling, marine cloud formation, and CCS (see Part II B (8) above on ocean-based climate-change mitigation), as well as land-based activities.

Overexploitation entails over-extraction or overuse of any marine living or non-living resource, service, function or amenity that can thereby be diminished in quantity or quality such that the resource, service, function or amenity becomes unusable or disappears altogether. It is the overarching threat of overexploitation to seamount ecosystems and biodiversity that is posed by the activities described in the present paper, should any of them occur to excess – the definition of excess varying with the activity. Overexploitation covers the unsustainable extraction of living resources, and in that context it is the principal overarching threat to seamount ecosystems and biodiversity.

The LOSC (including the implementing agreement on straddling and highly migratory fish stocks) does not define overexploitation, but LOSC Art. 61 (2), for example, treats it specifically as a threat that "endanger[s]" the "maintenance of living resources". Overexploitation in ABNJ is addressed, *inter alia*, by LOSC Arts. 116-120, which require conservation and management of high-seas living resources and marine mammals, and by LOSC Art. 145, which requires protection of the marine environment in the Area, i.e., the seabed in ABNJ.

The LOSC distinguishes between but does not define ecosystem or habitat. It provides specifically for the protection and preservation of "rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life" (Art. 194(5)). The CBD defines habitat as "the place or type of site where an organism or population naturally occurs" (Art. 2; the CBD's definition of ecosystem is provided and discussed above in Part I D). Habitats form part of ecosystems; thus degradation of the former inevitably harms the latter (and *vice-versa*). It is useful to maintain a conceptual distinction between adverse effects on habitats caused by materially or tangibly physical forms of habitat destruction and degradation, such as those set out in Part II above (e.g., anchoring, cable/pipe-laying, grounding and shipwreck, mining, shading, washes and wakes, and the adverse effects on habitats of the other three overarching threats). However, when it is considered that the sheer quantitative removal from a habitat even of a single species can also cause habitat degradation or destruction (as well as overexploitation) – as can debris, light, noise, temperature, particles, pollution, etc. (see Part II above) – the distinction becomes difficult to maintain at an operational level.

Although the detailed interaction – feedback loops – among this quartet of overarching threats is poorly understood, it is apparent from Part II that these threats usually overlap in, as well as exacerbate, their individual deleterious effects on marine ecosystems, biodiversity and environment, including seamounts. It is highly likely that their detrimental effects are synergistic and cumulative. Moreover, it is becoming increasingly evident that all marine ecosystems and habitats are essential to all marine species at some point in their life cycle. Therefore, at the operational level, marine ecosystems and habitats are no longer usefully distinguishable *inter se* or separable from the ocean basin as a whole, if the objective is to effectively protect them. Consequently, the fundamental, cumulative and synergistic effect of the other three overarching threats is to degrade, fragment and destroy habitats and ecosystems on an oceanic – that is, basin-wide – scale.

The concepts of assimilative or carrying or regenerative or absorptive capacity of an ecosystem, which – at least as far as the ocean is concerned – were assumed in human expectations to be almost infinite, are obsolete. Furthermore, ecosystem change in response to threats is often neither linear nor gradual. It tends to occur abruptly or accelerates once a threshold is crossed. This threshold is called the tipping point. After the tipping point has occurred, recovery or rehabilitation of the resource, the habitat, the ecosystem, is virtually impossible. Even if it were possible, it would be prohibitively expensive. The marine environment is particularly susceptible to tipping points. This vulnerability to catastrophic, irreversible changes in structure and function is related to a history of multiple, interacting anthropogenic threats and their effects that may seem to cause 'only' 'small' incremental changes, but which in fact decrease resilience to environmental changes to such an extent that only a minor additional stress triggers a whole-scale collapse. The collapse in 1994 of the Grand Banks fishery is an instructive and sobering example.

A major conclusion of the Millennium Ecosystem Assessment is that the occurrence of tipping points in the marine environment is at present unpredictable. This is another consequence of the knowledge gap identified in Part III. All the activities set out in Part II above already, to a greater or lesser extent, occur throughout, and concomitantly threaten, the oceans. Many of their adverse effects (there may be yet more than we know) on the marine environment, its ecosystems and biodiversity are known and evident. The scale of the cumulative anthropogenic burden now being placed on the oceans may already be so great that there may no longer be an ascertainable threshold of human-induced threats and effects on these ecosystems from which, once breached, they could still recover. This situation is likely to be applicable to seamounts as well, and even, or perhaps especially, to those seamounts that are far from land in ABNJ.

Seamount ecosystems are considered to be particularly fragile and vulnerable to anthropogenic threats. The range of activities set out in Part II is extensive enough and their adverse effects on other ecosystems, if not on seamounts themselves, are sufficiently well known that it would be reasonable to surmise that all aspects of the seamount's ecosystems and biodiversity could be placed at risk if these activities were to occur in the vicinity of seamounts. Any additional or new activity, or the intensification of an ongoing activity, could even become the tipping point for the collapse of a seamount ecosystem. At present an objective comparator of the threats and effects associated with the activities listed in Part II in this regard is lacking. This would be provided by a mechanism to improve the predictability of the tipping point trigger(s) or, as proposed in Part III above, to improve the quantification of the risks thereof for seamount ecosystems.

V. CONCLUSIONS

Seamount biodiversity and ecosystems appear to be "heir to a thousand [un]natural shocks", to paraphrase Hamlet, whose gloomy outlook finds some justification when applied to seamounts. They are already subject to chronic stresses both from shipping and from non-shipping activities that have global effects. Superimposed on these chronic stresses are the stresses from potential, emerging and actual activities for which shipping serves primarily as a platform; these additional stresses can be acute and become chronic. None of the activities operate in an otherwise pristine and unstressed (threat- and effect-free) environment. They can and often do interact, with cumulative and synergistic adverse effects on the seamount environment, which is all the more worrying because the details of the interactions are poorly understood. Therefore none of the activities should be considered in isolation in assessing its potential consequences for seamount biodiversity and ecosystem health. Pollution, overexploitation and IAS essentially combine to degrade, if not destroy, ecosystems, and they operate on an oceanic – that is, basin-wide – scale.

Seamount ecosystems are particularly fragile and vulnerable to anthropogenic threats and hence to tipping points. Any additional or new activity, or the intensification of an ongoing activity, could become the tipping point for the collapse of a seamount ecosystem. An objective comparator of the threats, effects and their interactions associated with the activities in this regard is lacking. This fundamental knowledge gap would be filled by a mechanism to improve the predictability of the tipping point triggers and to improve the quantification of the interactive risks thereof for seamount ecosystems and biodiversity. Otherwise, the sheer multiplexity of the effects of anthropogenic activities on seamount ecosystems and biodiversity are unlikely to be manageable. As Hamlet said: "When sorrows come, they come not single spies, but in battalions."

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Chapter 2 – Fisheries and Aquaculture

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I. Fisheries

A. Introduction

Sections II (B) and II (C) of companion Volume 1, 'Overview of Seamount Ecosystems and Biodiversity', provide descriptive information on the deep-water fisheries of Indian Ocean seamounts. This chapter presents a generalized account of threats to seamount ecosystems by these and other types of fishing operations. Some of the information presented here originates from studies undertaken or data obtained from outside the Indian Ocean, but whose findings are relevant to the region.

Interactions between seamounts and underwater currents, as well as their elevated position in the water, attract plankton, corals, fish and marine mammals alike. Seamounts create complex current patterns that can influence the behaviour and distribution of the marine life on and above them. Interactions between currents and topography on seamounts include semi-stationary eddies (Taylor columns)[1], internal wave reflection, tidally induced currents and eddies, trapped waves, and eddies shed downstream. Isotherms are also uplifted over seamounts, resulting in the introduction of nutrients into surface waters where plankton development is often nutrient-limited. Due to these strong localized currents and upwellings, the biomass of plankton, including fish larvae, is often high over seamounts (Boehlert and Genin, 1987).

The diurnal movement of planktonic organisms that makes up the deep-scattering layer (DSL) also contributes to high seamount productivity. The DSL rises in the water column during the night, during which time it is horizontally translocated by ocean currents. DSL organisms seek to descend again in the early morning, but those that are transported to the vicinity of seamounts are unable to reach deep water and instead become prey to pelagic and benthic-feeding seamount-associated predators. Many benthic invertebrates found on seamounts are suspension- or filter-feeders which are adapted to capture this food source; they include stony corals, gorgonians, black corals, sea anemones, sea pens, hydroids, sponges, sea squirts (ascidians) and crinoids. Fish and non-benthic invertebrates also exploit this food source: Rogers (2006) notes "…reports of extremely dense shoals of lantern fish, mysid shrimps and squid that feed above seamounts at night but which live close to the sides of seamounts during the day. These species appear to feed on vertically migrating oceanic plankton that maybe become trapped above the seamounts. In turn, they form a food source for larger, commercially valuable species of pelagic fish such as sharks, rays, tuna and swordfish".

There is thus a regular inflow of prey to seamount areas, although in many cases this is periodic rather than constant. The nutrient and food supply allows seamounts to attract and maintain large populations of commercially useful fish and other organisms, some of which may be permanent and others transitory. Seamounts have been shown to concentrate pelagic plankton and to attract aggregations of fish, birds and mammals.

The fish aggregating effects of seamounts have long been noted by the commercial fishing industry, and many seamounts are or have been extensively exploited. Some 80 fish species are commercially harvested from seamounts, including orange roughy, oreos, rockfish and alfonsino. Lobsters, deep-water corals and other commercially valuable species are also targeted by specialized fishing operations.

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[1] A Taylor column is a result of the Coriolis force, which causes moving objects on the surface of the Earth to appear to veer to the right in the northern hemisphere, and to the left in the southern. Rotating fluids that are perturbed tend to form columns parallel to the axis of rotation, called Taylor columns. A rotating fluid has a specific kind of rigidity and no longer acts quite like a fluid. An opposing view holds that open-ocean waters are normally nutrient deficient, and nutrients released from open-ocean aquaculture operations may increase wild production in adjacent areas. See: **http://onf-ocean.org**, **http://sydney.edu.au/science/usims/ocean_technology/research/nourish.shtml**, **http://sydney.edu.au/science/usims/ocean_technology/research/kenya.shtml** and **http://www.subsistencefishingfoundation.org**.

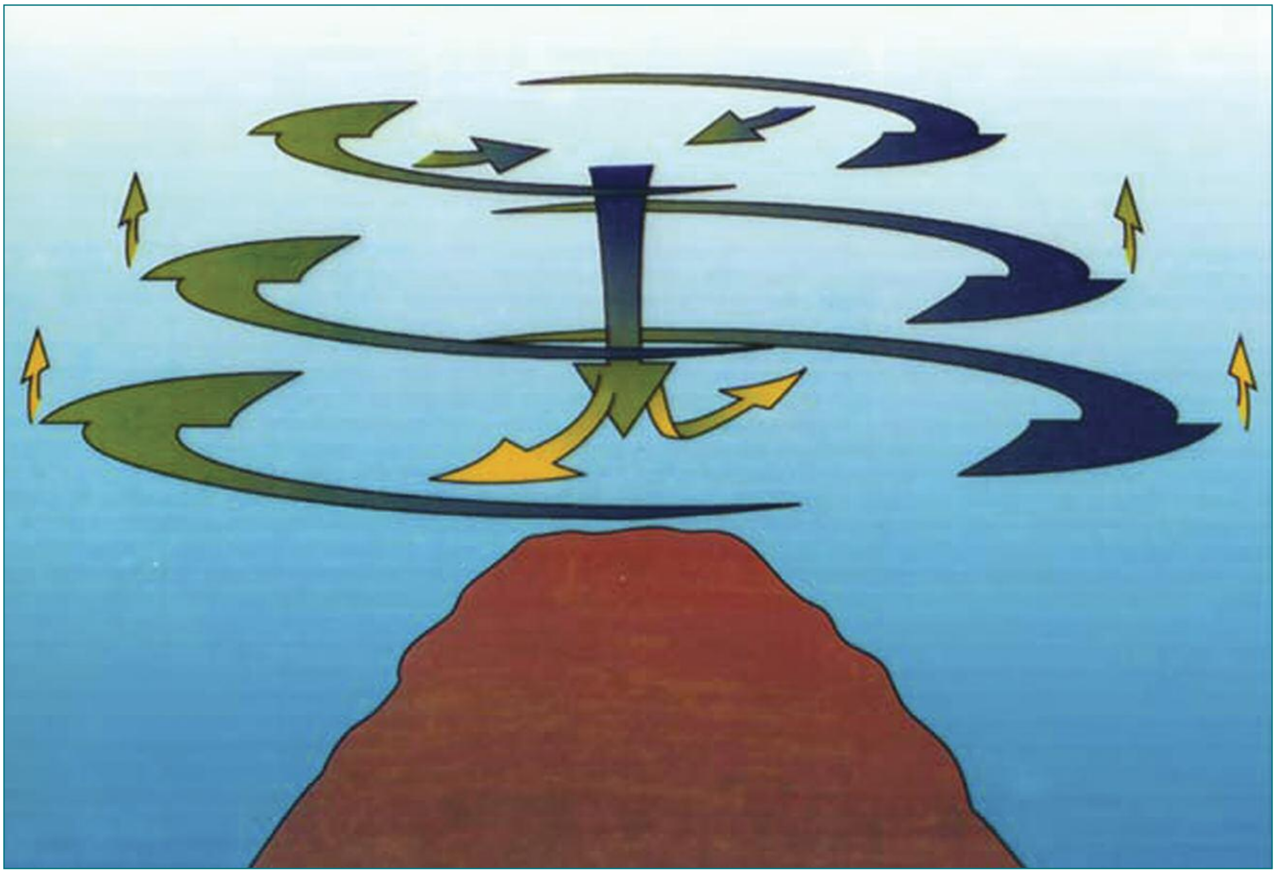


Figure 1: Circulation around a seamount summit (not to scale). The circular flows run clockwise, decreasing in strength with height off the bottom. There is a strong lateral flow outward near the seamount summit, with weaker inward flows higher up. Vertical currents are strongly downward near the centre and weaker and upward near the periphery. Larvae caught in this flow pattern might easily complete their development near the seamount summit. (From a study on currents and larval settlement at Fieberling Guyot, a Pacific seamount, by Mullineaux, L.S. and S.W. Mills (1997), cited at http://oceanexplorer.noaa.gov/explorations/03mountains/background/larvae/media/circulation.html)

Depletion of many inshore and shelf groundfish stocks in the 1990s encouraged fisheries to expand into deeper water and, in particular, to seamounts. Since the 1970s, advanced gear technology has enabled fishing in deeper waters and on small, steep and rough seamount flanks that were previously too difficult to fish (Pitcher *et al.*, 2010). Kitchingman and Lai (2004) used mid-resolution bathymetric data to estimate the number of seamounts globally (around 14,000). Based on this information, Guinotte (undated) estimated the number of high-seas seamounts in the Indian Ocean to be 1,203, of which 268 could be fished using currently available technology, the other 935 too deep (over 2,000 m) to fish at the present time. The same author noted that there are 39 seamounts within the proposed SIODFA Benthic Protected Areas (see Section II (C) of companion Volume 1 for description), of which 15 are fishable and 24 are too deep to fish using current technology.

The main types of fishing operation practised on seamounts can be categorized as:

- deep-water fisheries, which involve direct contact between the fishing gear and the benthos of the seamount: bottom-trawling, bottom-set gill-netting, bottom longlining, trap-fishing, dropline fishing and coral harvesting; and

- surface and mid-water fisheries, in which the gear does not (intentionally, at least) come into physical contact with the seamount benthos: mid-water trawling, longlining and purse-seining.

There have been surprisingly few studies on deep-water fishing impacts, especially on seamounts, given the amount of fishing conducted on them in recent years (Pitcher *et al.,* 2010). There are nevertheless serious ongoing concerns as to the negative effects of fishing on seamount ecosystems, which relate primarily to the following issues:

- Stock depletion. Seamount fisheries are usually boom-and-bust fisheries, in which standing stocks are quickly depleted by intensive fishing, after which the fishing operation moves to a new seamount. There are well-documented cases of stock decline, for example with the orange roughy (*Hoplostethus atlanticus*);
- Physical damage to benthic ecosystems caused by trawls and traps dragging across the seafloor, or by entanglement of nets and lines;
- Alteration of pelagic, mesopelagic and benthic ecosystems through the selective removal of target species and associated by-catch species; and
- Other impacts that may be caused by discards of unwanted or excess catch, noise disturbance by sonic equipment used in fishing, ghost fishing by lost or discarded fishing gear, and issues specific to certain fisheries, such as those for deep-water corals.

These impacts of fishing operations are discussed in more detail in the following paragraphs. More generalized impacts caused by fishing vessels themselves are similar to the impacts of shipping, described in Chapter 1 (Section II (A)).

B. Stock depletion

Over-fishing of coastal stocks has created new pressures for the fishing industry to locate alternative fishing grounds. In particular, seamounts are relatively newly targeted ecosystems that have become increasingly fished since the second half of the 20th century. Watson and Morato (2004) state: "Expansion of commercial fisheries into deep-water areas, especially those outside the jurisdiction of current management agencies, is one of the most worrying developments in recent years." Seamount fisheries typically exhibit a boom and bust sequence, crashing within about ten years of their initial development. This was the case with the orange roughy fisheries off New Zealand, Australia and in the Atlantic, the pelagic armourhead (*Pseudopentaceros wheeleri*) fisheries over seamounts in international waters off Hawaii, and the blue ling (*Molva dipterygia*) fisheries in the North Atlantic. As seamounts are rapidly depleted, the continued existence of the fisheries on them depends upon the discovery of unexploited seamounts with large fish concentrations.

The species targeted by seamount fisheries often have a low overall abundance, but may aggregate at seamounts as certain stages of their life cycle strategy, such as for spawning. In many cases they are long-lived, slow-growing, late-maturing (at about 30 years) and have low reproductive potential. If fished out, it could be decades before these localized stocks recover, particularly as they may have limited exchange with other seamounts.

Unregulated small-scale fishing can also disturb these sensitive environments, as has been demonstrated by the decline of important seamount fish stocks exploited by small-scale handline and bottom longline fisheries in the Azores and in Tonga. However Pitcher *et al.* (2010) state: "Small-scale artisanal fisheries using less harmful fishing gear, spatial closures, and low catch levels provide an attractive model for improved seamount fishery management that could foster the reconstruction of previously damaged seamount ecosystems."

C. Physical damage to benthic ecosystems

Bottom-trawling as a fishing method is widely criticized among the fisheries management and conservation communities because of the damage it causes to benthic ecosystems (see for example Jacquet *et al.*, 2010). Bottom-trawling can damage ecosystems by literally scraping away sections of seafloor and removing habitat-forming organisms and their associated communities. The ground gear used to protect the deep-water trawl nets from damage on the rough seafloor is large and heavy, and as well as the obvious direct impacts caused by physical disruption, there are also indirect effects such as sediment re-suspension and mixing (Pitcher *et al.,* 2010) and attraction of predators and scavengers. Seamount topographies, along with navigation technology, result in a large number of trawl tows over a relatively small area, and with the heavy trawl gear used in the fisheries this produces intense local disturbances (Smith, 2002). Such massive removal of natural and structural components of the ecosystem has highly negative consequences for seamount biodiversity.

Sessile fauna such as deep-water corals, which form reef-like structures on the summits and upper flanks of deep-water seamounts, are particularly vulnerable to damage by trawling operations. The bushy tree-like form of many seamount invertebrates, which are often adapted to filter-feeding, makes them easily prone to breakage by ground gear. These animals form biogenic habitat for many other species, and may be slow-growing and hundreds of years old, so any recovery from impact is slow. Studies of the by-catch taken in orange roughy fisheries clearly show that habitat-building corals such as *Solenosmilia variabilis* are removed by trawling (Anderson and Clark, 2003). This has been quantified in various studies, including a comparison of the catch composition of corals in six trawls from unfished seamounts (total coral catch 3,000 kg) and 13 trawls on fished seamounts (5 kg coral) on the northwest Chatham Rise of New Zealand (Clark *et al.*, 1999).

On Tasmanian seamounts, Koslow and Gowlett-Holmes (1998) recorded major impacts on biodiversity within a few years of the development of the orange roughy fishery. On heavily fished seamounts (more than 1,000 individual trawl operations known to have occurred) reef aggregate had been removed or reduced to rubble, the invertebrate biomass was 83% lower, and the number of species 59% lower than on lightly fished seamounts (10-100 trawls). Intense fishing effort over a sustained period of time is clearly deleterious, but even 'light' trawling can have significant and perhaps irreversible effects on the habitat and ground cover provided by benthic organisms. For example, although trawling may not completely remove coral, repeated damage to coral colonies over time can reduce their size to a point where sexual reproduction of dispersive larvae is no longer possible (Rogers, 2004).

The wide but discontinuous distribution of seamounts creates unique problems for the dispersal and recruitment of seamount-associated fish and invertebrates, with potential loss of larvae and juveniles from the local environment. Different species have evolved different strategies for dispersal from and recruitment to seamount environments. Even amongst the commercially important teleosts, some species, such as armorhead, alfonsino and oreo, have extensive ocean-wide pelagic juvenile dispersal and recruit to distant sea mounts, while orange roughy have limited dispersal with a short larval stage and assumed benthic juveniles. These different dispersal patterns are reflected in levels of genetic differentiation between populations, with low differentiation in oreo and higher differentiation in orange roughy. Species with narrow dispersal capabilities will be more vulnerable to localized depletion (Smith, 2002).

Many of the commercially important seamount fishes have ocean-wide distributions, but a high degree of endemism of both invertebrates and small benthic fishes has been reported among seamounts. Around 15% of the 597 species, mainly megafauna, that occur on seamounts globally are considered to be endemic (Wilson and Kaufman, 1987). Some studies on Australian seamounts indicate much higher levels of endemism (United Nations, 2006). For example, in just one expedition to the Tasman and Coral Seas in the South Pacific, scientists reported that 16-36% of the 921 species of fish and other benthic macrofauna collected on 24 seamounts were new to science (United Nations, 2004). On 14 seamounts off southern Tasmania 24-43% of the species sampled were new to science and 16-33% were endemic (Koslow and Gowlett-Holmes, 1998). Low species overlap was found between seamounts in different portions of the region, suggesting that these seamounts function as islands or chains, with important consequences for speciation (Baker *et al.,* 2001). Given the relatively high levels of endemism of seamount faunas, especially those associated with cold-water coral reefs, coupled with the somewhat limited dispersal ranges of some species, it is likely that trawling activities have already destroyed many benthic seamount communities, with as yet undetected impacts on the wider ocean ecosystem (Rogers, 2004).

The physical impacts of other deep-water fishing methods are less dramatic than those associated with trawling, but still have the potential to cause unwanted impacts. Dropping of traps or pots for lobsters or fish is prospectively a technique that could cause cumulative damage to habitat-forming corals over time, but is not known to be practised to any great degree on seamounts at the present time. Bottom-set gill-nets, demersal longlines and hand-line gear used for bottom fishing all carry lead weights that can cause damage to corals during the setting and hauling operation, or if dragged across the seafloor by currents. If the gear becomes tangled then efforts to free it by brute force can lead to additional breakage of corals and damage to other benthic organisms. However, the practicalities of operating these types of fishing gear mean that all but the shallowest seamounts are essentially unfishable at the present time. The UN (2006) states that "while there is some evidence to suggest that bottom-set longlines, bottom-set gillnets, pots and traps (including when 'ghost fishing') all may be impacting the deep-sea, bottom trawling and dredging appear to be having the most obvious disruptive impact due to their widespread use and their contact with the bottom".

D. Target species and by-catch

All fisheries selectively remove certain species from the ecosystem they exploit, and thus by their very existence cause alterations to marine community and ecosystem structures.

In the case of deep-water trawling, some of the corals and other benthic organisms that are broken by the physical action of the fishing gear will be incidentally harvested as part of the catch. Trawl by-catch also includes various other species

A fish skeleton caught in a ghostnet.
© Sijmon de Waal/Marine Photobank

of fish, as well as invertebrates (lobsters, squid, mysid shrimps), some of which may have commercial value, others of which will be discarded as 'trash'. In New Zealand, trawl by-catch from seamounts included large epibenthic cnidarians (black corals, true corals and sea fans), echinoderms (starfish, sea lilies and brittle-stars), arthropods (stone crabs and true crabs) and molluscs (gastropods, octopus and squid), many of which were new to science (Smith, 2002). In the Indian Ocean, trawl by-catch may be expected to include a wide range of benthic invertebrates and fish, as well as occasional takes of sensitive or vulnerable species such as benthic sharks. Trawl fisheries in general are notorious for taking and discarding large amounts of by-catch. Shrimp fisheries in particular may have by-catch rates which exceed the catch of target species by up to 20:1, with an overall (global) average of 5.7:1 (Clucas, 1997). Trawling for finfish produces lower, but still sometimes significant, volumes of by-catch.

Other fishing operations also exert their toll in terms of by-catch. Pelagic and bottom longlines, as well as handlines and baited traps, all take a wide variety of fish species, almost invariably apex predators because of their use of bait. Purse-seine fishing in the Indian Ocean targets surface-swimming tuna schools, but there is usually an incidental catch of non-target species that includes other finfish, sharks and, occasionally, sea turtles and marine mammals. The selective removal of these species has ecosystem impacts through its effects on predator-prey relationships, and possibly other mechanisms, which at present are poorly documented.

E. Discards

It is worth making the distinction between 'by-catch', meaning the incidental capture of non-target species, and 'discards', which means catch that is unwanted and usually thrown overboard while at sea. Not all by-catch is discarded – some has commercial value and is retained (e.g. crayfish and some large fish species sometimes taken in prawn trawls). Conversely, not all discards are by-catch – sometimes some of the target species are thrown overboard in order to make space in the fish holds for more valuable catch, or to comply with quota requirements or other management measures. 'High-grading' is a particular category of discarding, whereby low-value target species (e.g., small size classes) are retained at the beginning of the fishing trip but may be discarded later if a good catch of larger fish is taken and storage space becomes limited.

Discarding usually takes place at the conclusion of each fishing operation, while the catch is being sorted and processed or stowed. However, this is not always the case – high-grading involves throwing overboard fish which had previously been retained, but which are now being discarded in order to free up storage space for more recently caught higher-value species or size ranges. High-grading may involve discarding large volumes of already-frozen catch from freezer wells, sometimes along with the brine (usually a strong calcium chloride solution) in which it has been frozen. Discarding may thus involve throwing overboard several tens of tonnes of fresh or frozen catch, sometimes along with freezer brine.

There is little or no data on the geographical distribution of discards from fishing operations, but it seems likely that discarding must occur above or in the vicinity of seamounts. Trawlers operating close to seamounts almost certainly discard in their vicinity. Because seamounts are known to act as an aggregation point for tuna schools, purse-seiners also regularly search and fish these areas, and may discard in their vicinity.

The impacts of discarding on or around seamounts are unknown, but the practice may be predicted to have consequences similar to those observed in coastal areas: attraction of scavengers, putrefaction of decaying fish on the seafloor, and consequent impacts on benthic fauna through deoxygenation, bacterial infection and physical burial. In areas of strong currents, the impacts of the discarded product may be attenuated to some degree through dispersal, but discarding still represents a point source of intense organic pollutants. As many seamounts are thought to have current systems which retain plankton and fish larvae, it might be expected that pollution and putrefaction products may also be retained in the seamount vicinity rather than being rapidly dispersed.

F. Ghost fishing

Several fishing methods utilize gear and equipment such as gill-nets, traps and pots that may continue to fish after being discarded or lost. This results in fish being removed from the population as in a normal fishing operation, although they are not actually harvested. Most fishing gears of this type will deteriorate over time, through tangling (in the case of gill-nets) or physical breakdown (all types), causing the degree of ghost-fishing to progressively diminish. The degree to which ghost-fishing is an issue on seamounts is not known but is thought to be relatively small. The primary fishing gears used on seamounts – trawls, purse-seines and longlines – involve active or baited gears which do not continue fishing after being lost or discarded.

G. Noise and acoustic devices

Most modern fishing vessels employ acoustic devices (echo-sounder and sonar) to monitor water depth, bottom contour and composition, and to detect fish biomass, which is then targeted using the fishing gear. Sonar devices are also deployed on the head-ropes and foot-ropes of trawls to help the operator determine the distance of the net from the seafloor and the gape of the net's mouth. Acoustic technology has been one of the most important driving forces behind the development of the modern commercial fisheries.

Fish finders and most commercial depth sounders operate at high frequencies. Usually, but not always, they project a lower power signal and have narrower beam patterns and shorter pulse lengths (a fraction of a second) than military sonars. Fish-finding sonars operate at frequencies typically between 24 and 200 kHz, which is within the hearing frequencies of some marine mammals, but above that of most fish. Globally there are a great many recreational, fishing and commercial vessels, most of which are fitted with some sort of sonar. Usage occurs throughout the year and both by day and night. Some horizontally-acting fish-finding sonars work at frequencies at the lower end of the 'high-frequency' range and are relatively powerful. ICES (2005) states that "the body of data currently available on the response of fish to sounds is not yet sufficient for developing scientifically supportable guidance on exposure to sound that will not harm fish. Nor is it possible at present to propose detailed measures for mitigation of the impact of sound".

Active sonar may harm or interfere with the behaviour of marine animals. Most marine mammals, such as whales and dolphins, use echo-location systems (sometimes called biosonar) to locate predators and prey. Active sonar transmitters can confuse the animals and interfere with basic biological functions such as feeding, mating and migration. Exposure to high-intensity noise can cause a reduction in hearing sensitivity (an upward shift in the threshold of hearing) but this impact is unlikely from the types of sonar used by fishing vessels. Intense sonar from military sources has been observed to cause physical damage, including internal bleeding, to cetaceans (Jasney *et al.*, 2005).

Recent technological advances have seen the development of sonic deterrent and monitoring devices for use on longline fishing gear. These include: sonic deflectors (passive devices for attachment to the longline) which confuse marine mammals and reduce depradation of longline catches by pilot whales and other cetaceans; and sonic monitoring buoys, which alert the longline operator to the presence of cetaceans within 80 km of the fishing vessel, so that the vessel can avoid deploying the fishing gear in these areas. While these devices are intended both to reduce fishery losses through cetacean depradation and to avoid interactions between fishing gear and marine mammals, their broader effects or impacts are unknown (Anon, 2010).

H. Harvesting of genetically unique resources

Current threats to the genetic diversity of seamount populations are principally from over-fishing or destructive fishing activities, as discussed above (see Sections I (B) stock depletion and I (C) physical damage to benthic ecosystems). Reduction of population or ecosystem diversity may result in a corresponding decrease in genetic diversity in the populations or ecosystems concerned.

Because of their relatively high levels of endemism, as well as the large number of new species continually being discovered there, seamounts undoubtedly serve as a repository of new or unfamiliar genetic material. Prospecting for genetic resources on seamounts (for purposes of fish stock improvement, identification of biochemicals with new properties, or genetic engineering) is not widespread at present, but may increase in the future. Development of such activities needs to take place in a manner that is both environmentally responsible and recognizes the rights and authority of resource owners or, in the case of the high seas, broader public interest in common property resources (Greer and Harvey, 2004).

I. Deep-water corals

Small, specialized dredge or ball-and-net fisheries for deep-sea corals exist in a small number of locales. The fishing methods used break and capture pieces of pink, black or other deep-water corals that can be used in making jewellery. These are generally artisanal or small-scale operations situated in areas where there is a well-developed local tourist market that can absorb the product. It is not known whether fishing operations for precious corals take place on Indian Ocean seamounts. If they do they are likely to be small and relatively unimportant.

Of far greater concern than targeted fishing for precious corals is the incidental damage done by bottom-trawling for fish on seamounts. As noted in Section I (C) above, large areas of deep-water corals are known to have been destroyed by bottom-trawling operations, and this is continuing in an indiscriminate manner. Clark *et al.* (2006) propose measures to improve knowledge and management of coral populations on seamounts through more comprehensive data reporting from commercial fishing fleets, stronger enforcement of compliance requirements, strengthening of regional fisheries management organizations and improved dialogue between science, industry and civil society. Roberts and Hirshfeld (undated) go further, demanding a prohibition of trawling in currently untrawled areas potentially containing coral communities, closure of some areas currently damaged by trawling, restoration of damaged areas, and more severe penalties for non-compliance by fishing vessels.

J. Marine aquarium trade

Almost all marine aquarium species are taken from the wild, with few examples of captive breeding. Tropical coral reefs are the most important source of specimens for the aquarium trade – mainly fish, including seahorses, the corals themselves, and others such as anemones, starfish and giant clams. Collection of ornamental species also occurs in other areas, including temperate oceans and freshwater bodies. In most cases collection of ornamental species is done by small-scale fishers, often using diving gear, in labour-intensive fishing operations.

As far as is known, there is currently no significant collection of ornamental species for the aquarium trade from seamounts, due to their depth and relative inaccessibility. In the event that this industry does ultimately develop in seamount areas, the threats will be similar to those experienced in areas where the industry already exists, namely: over-fishing, use of destructive fishing practices and (possibly) population modification through sex-selective harvesting of key species (Wabnitz *et al.*, 2003).

K. Sports/recreational fishing

Recreational fishing on seamounts is limited primarily to 'blue-water' sports fishing for large pelagic apex predators such as marlin, tuna, dolphin fish and sharks. These are the same species as those targeted by longline fishing operations. Sports fishing is often viewed as a 'greener' way of using this resource, given the large economic multiplier that applies per fish caught: the returns on longline-caught fish may be of the order of a few dollars per kilo, whereas sports fishing is often associated with tourist spending on associated services and supplies. Development of locally-based sport-fishing industries is a target of many small-island developing States, including those in the Indian Ocean, and sport-fishing clubs exist in all western Indian Ocean countries. Those seamounts within a few tens of kilometres from the shore are natural targets for sport-fishing activities because of their fish aggregating effects, described above.

The impacts of recreational fisheries on Indian Ocean seamounts are relatively limited: there is little or no use of destructive fishing gear or techniques, little or no discarding, and catches are orders of magnitude lower than those of commercial or industrial fisheries. Many sports fishing operations, especially those that target the tourist market, operate a catch-and-release policy, so fishing mortality is limited. Selective removal of apex predators may have unknown ecosystem impacts, but this is likely to be minuscule compared to those arising from longline fishing operations. Even with significant further development of this industry, it will pose far less of a threat to seamount ecosystems than commercial fishing.

II. Aquaculture

A. Introduction

Open-ocean aquaculture (OOA) refers to the rearing of marine organisms under controlled conditions in exposed, high-energy ocean environments beyond significant coastal influence. Proponents of OOA believe it is the beginning of the 'blue revolution' – a period of broad advances in fish culture methods which will lead to increased production, take pressure off wild stocks, avoid user conflicts, enhance recreational fishing opportunities and create new jobs. Critics raise concerns that such farms could harm the environment, put native fish at risk, pollute oceans with fish waste and excess food, and have negative impacts on existing commercial fisheries. The economics of many OOA systems have yet to be tested and in some cases it is hard to see how they could be profitable or cost-effective given the rigours and challenges presented by the open-ocean environment. In particular, great distance from shore significantly increases the investment requirements and costs of servicing offshore aquaculture platforms (Kite-Powell, 2008). There are also concerns that OOA activities will threaten existing jobs and livelihoods based on wild fisheries. Recent US plans to permit 5-20 deep-water aquaculture operations in the Gulf of Mexico have been criticized by more than 100 environmental and fishing organizations. These potential environmental and economic impacts and associated controversies have probably contributed to slowing the expansion of this sector.

The technology for OOA is relatively new and experimental or, in some cases, yet to move beyond the drawing board. Actual or proposed farming systems include cages, net-pens and longline arrays that can be free-floating, secured to a structure, moored to the ocean bottom or towed by a vessel. Research and commercial OOA facilities are in operation or under development in Australia, Chile, China, France, Ireland, Italy, Japan, Mexico, Norway and the USA. Many of these are trialling OOA technology in shallow or protected coastal waters prior to full-scale deployment in an oceanic environment, and most currently operating commercial facilities are in near-shore waters where they use cages moored to the ocean bottom. There has been some experimentation with offshore shellfish culture on suspended ropes and longlines, and offshore seaweed culture may also be considered (Borgatti and Buck, 2004).

Current research programmes are focussing on identifying appropriate farming species and developing culture techniques, including species selection, egg/larval production systems and nutritional/dietary requirements. Species currently being studied for possible culture include halibut, haddock, cod, flounder, blue mussels, black sea bass, mutton snapper, cobia, yellowtail snapper, amberjack, deepwater snappers, corvine, mahimahi, red drum, tuna and striped bass. Other research topics being investigated include:

- hatchery culture technologies;
- designs for automated feeders;
- culture of new species;
- identification and control of diseases; development of cages and husbandry technology for rough water environments;
- identification of alternative food sources;
- information on nutrition requirements;
- definition of carrying capacity of offshore waters;
- development of appropriate mooring systems;
- development of drifting and self-powered cages; and
- development of environmental monitoring systems and technology (Upton and Buck, 2010).

Proponents of open-ocean aquaculture and many environmental groups suggest that open-ocean finfish aquaculture systems may encounter similar, but fewer, environmental concerns than those experienced by near-shore aquaculture systems. This is in part due to the assertion that dissolved and particulate waste products and excess feed may be assimilated and recycled more efficiently in the open-ocean environment. However, the scope of any effects may vary greatly depending on the technique, location, size/scale of operation, and species raised. In addition, OOA involves less control over organisms and the surrounding environment than do inshore and land-based aquaculture, and may present fewer options to rectify environmental problems when they do arise. Critics of open-ocean aquaculture hope that regulation of this emerging industry will be stringent (Bridger and Reid, 2001).

Essentially, OOA is in its infancy and, although there are many pipeline projects, there are only a few actual operations currently in existence from which to draw lessons and information. The potential outcomes of OOA are difficult to generalize because of the diverse nature of possible operations and the lack of aquaculture experience in open-ocean areas. Environmental impacts are thus not known with certainty, although based on information from other types of aquaculture it can be speculated that they will include: the escape of fish, water pollution from uneaten feed and waste products, use of antibiotics and other animal drugs, alteration of benthic habitat by settling wastes, and the spread of waterborne disease from cultured to wild fish (Bridger and Costa-Pierce, 2003). Another issue, specific to OOA, is the potential for impacts on marine mammals and other sensitive species. In the event that OOA facilities ultimately develop in the vicinity of seamounts, in the Indian Ocean or elsewhere, environmental threats or impacts are likely to fall primarily into these categories, which are described in more detail below.

B. Feeding and waste disposal

All fish currently proposed for OOA are carnivorous, and farming of these species involves daily feeding with compounded feeds containing fishmeal and fish oil. Aquaculture feeds are produced primarily from fish caught from wild stocks, supplemented to some degree with vegetable-based protein or other products. Three or more units (by weight) of feed are required to produce one unit of farmed fish; hence there is a large amount of fish feed provided daily, much of which is excreted by the fish as waste products. A small amount of feed may go unconsumed and fall through the bottom of the cage or net, OOA facilities being open to the surrounding environment.

The degree to which this constant stream of waste is absorbed or attenuated by the surrounding marine environment will depend on the composition and health of the ecosystem and on current and water circulation patterns. If waste cannot be readily absorbed or attenuated, then a local over-supply may develop of nitrates, phosphates and other chemicals found in biological waste products. This may in turn promote eutrophication and impact on the availability of food and oxygen within the seamount ecosystem. In addition, solid waste products may accumulate on the seafloor and result in harmful effects on the benthos, caused by deoxygenation, putrefaction and bacterial contamination[2]. Further local impacts may occur if aquaculture operations on seamounts also begin catching fish locally to provide feed for farmed species, although this seems unlikely.

Another environmental concern is the use of pharmaceuticals, antibiotics, growth-enhancing chemicals, other animal drugs, and antifouling agents used on gear and enclosures in open-water environments. Drugs, some of which were developed and approved for use in a contained or controlled environment, are often introduced to cultured fish in their feed. The unconsumed feed, and the metabolic waste from the fish feeding on it, pass through and out of the containment system, where some of the artificial additives they contain may be consumed by wild organisms.

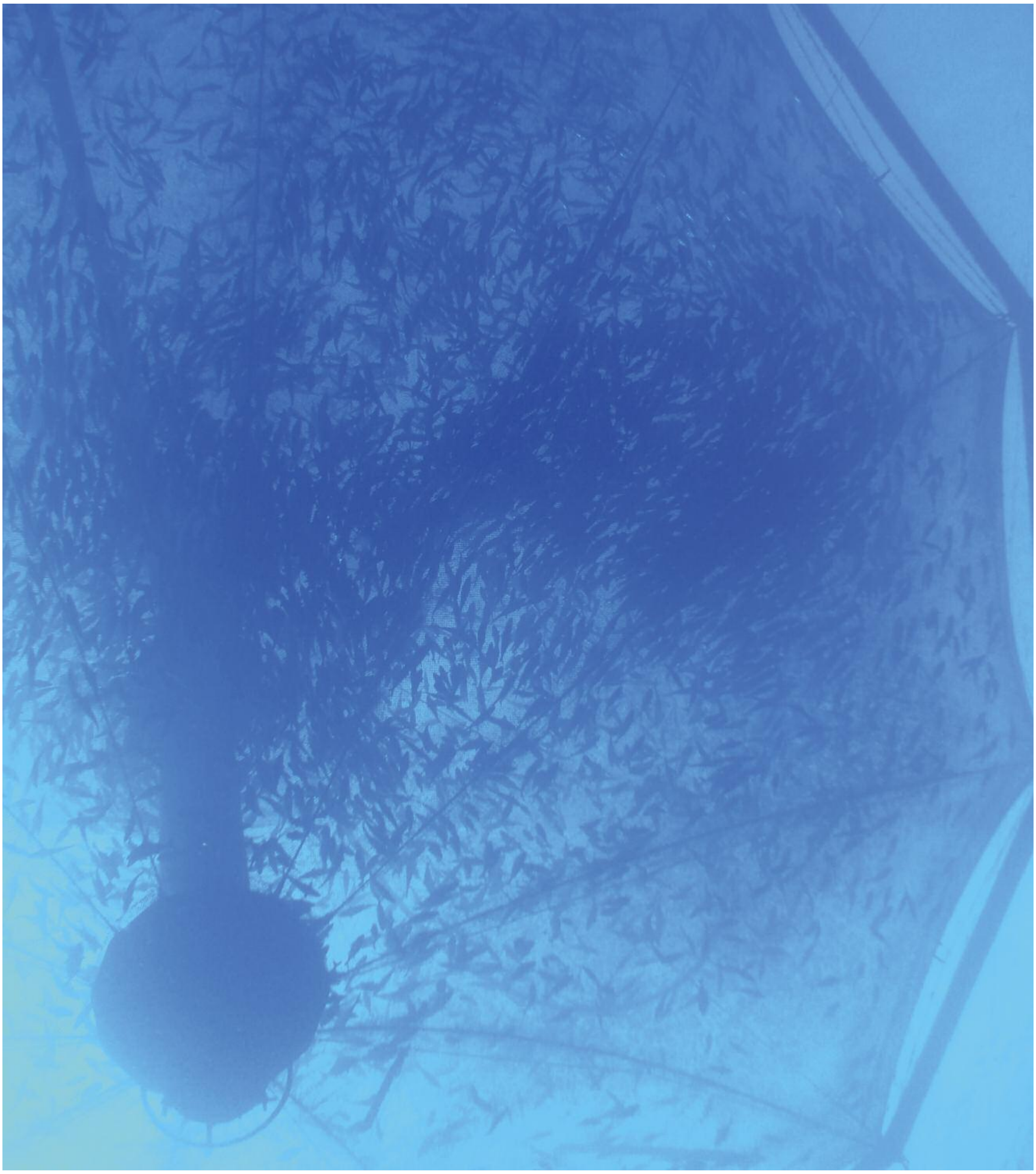
Open-water culture of molluscan shellfish may be more environmentally benign, as it does not usually involve feeding of the farmed animals. However, high stocking densities of filter-feeding molluscs still produce large volumes of faecal matter which, depending on local current conditions, may result in solid waste pollution problems similar to those described for finfish.

C. Disease

Fish kept under intensive farming conditions are more prone to epidemics of diseases or parasites than they are in the wild. This is because the fish themselves are usually stressed and prone to

[2] An opposing view holds that open-ocean waters are normally nutrient deficient, and nutrients released from open-ocean aquaculture operations may increase wild production in adjacent areas.

infection because of overcrowding and unnatural feeding regimes; and the high stocking densities under which the fish are kept provide ideal conditions for infections to spread. Many aquaculture operations use veterinary drugs in the fish food or applied directly in the water (sometimes in contravention of aquaculture regulations) to control disease and parasite infection. Because of the open nature of the cages or pens in which the farmed fish are kept, diseases and parasites can easily be transferred to fish in the wild, and there are numerous



Open-ocean aquaculture. © Kydd Pollock/Marine Photobank well-documented cases of this in regard to the salmon-farming industry, where sea lice from farmed fish in cages have infested wild populations. (Disease may also spread from wild populations to farmed fish: outbreaks of infectious hemato-poietic necrosis virus in farmed salmon have been confirmed to have originated from wild fish).

Another concern involves the spread of fish-borne disease and genetic anomalies that could possibly occur if wild fish are exposed to or interbreed with hatchery-raised fish. This issue might arise if genetically modified or non-native fish escaped from aquaculture facilities and interbred with wild fish. Critics speculate that, since selectively bred and genetically modified fish may grow faster and larger than native fish, they could displace native fish in the short term (both through competitive displacement and interbreeding), but might not be able to survive in the wild for the long term. This is especially a concern in US states such as California, Maine, Maryland and Washington, where genetically modified fish are banned within state waters but could be grown offshore in federal waters. A related concern is the introduction of exotic species, such as Atlantic salmon in British Columbia. Escaped fish could be a problem in open-ocean facilities battered by storms. The experience with salmon farming indicates that escaped fish could easily be a problem, either through interbreeding with closely related native species (genetic interactions) or through competitive displacement of native species. Although management techniques at net-pen sites are improving and modified cage designs better prevent escapes, closed containment systems may be the only way to address this problem. Problems with the transfer of sea lice from salmon farms to wild salmon have been noted recently.

D. Escapes

Escapes of fish are inevitable from a fish pen or cage floating in the open ocean, especially during periods of storms or rough weather. Concerns regarding escapes are threefold:

- Escaped fish may be of a species that is non-native to the seamount environment, but which may adapt and become invasive, out-competing and displacing native species;
- Escaped fish could interbreed with closely related native species, affecting the genetic integrity of the local population; and
- Genetic anomalies in local fish populations could occur if wild fish interbreed with hatchery-raised fish, especially genetically modified ones. Critics speculate that, since selectively bred and genetically modified fish may grow faster and larger than native fish, they could displace native fish in the short term (both through competitive displacement and interbreeding), but might not be able to survive in the wild for the long term.

There are numerous examples related to coastal and terrestrial aquaculture in regard to each of these concerns.

E. Endangered and sensitive species

Since OOA facilities will be offshore and underwater, possible harm or disturbance to marine mammals and other wildlife are a concern. Experience has shown that dolphins and other marine mammals do get entangled in fish farms. To address these concerns, current cage designs for finfish avoid the use of small-diameter or loose lines or loosely hung netting which could lead to entanglement of sea turtles and marine mammals in net-pens and associated gear. Shellfish farms have many ropes and longlines, and could be more problematic.

Sonic devices are used by some aquaculture facilities to keep certain types of nuisance animals at bay, and these could harm marine mammals. Open-ocean facilities could potentially affect some endangered species, such as whales, as they migrate, or could alter essential habitat for feeding, breeding and calving. There could also be incidence of killing 'problem' animals, as has been the case with salmon farmers killing seals and sea lions. This might extend to other predatory animals such as sharks; great white sharks, an endangered species, have found their way into tuna farms in Australia on several occasions, for instance.

III. Ocean Fertilization

Several private or quasi-private groups have proposed large-scale experiments to fertilize the surface waters of large areas of ocean in order to promote algal growth in nutrient-limited oceanic waters as a means of sequestering carbon from the atmosphere. The theory is that small amounts of nitrogen, phosphorous or iron can be added to waters lacking these nutrients, and the subsequent growth and then sinking of algae will carry large amounts of carbon into deep water and remove it from the atmospheric cycle. Modelling indicates that one atom of nitrogen, phosphorous and iron would sequester 6,100 and 10,000 atoms of carbon respectively; hence most interest has focused on iron fertilization (using soluble iron compounds, not iron filings). However, a recent review of these ideas, most of which have not succeeded in getting beyond the proposal stage, finds that: there are numerous untested assumptions in regard to the actual fate of the carbon removed from surface waters using this technology; and the complex trophic structures typical of ocean food webs make the ecological impacts and their consequences for nutrient cycling and flow hard to predict. Ocean fertilization is considered likely to be feasible but not very effective; to have low long-term carbon storage potential; to not be cost-effective; to require substantial prior research for investigation of environmental impacts, efficacy and verifiability; and to have high potential for unintended and undesirable ecological side effects, including possible creation of new anoxic regions of ocean ('dead zones') and slightly increased acidification of the deep ocean. With these drawbacks, "societal and political acceptance is likely to be low" (Royal Society, 2009).

A number of university research projects and civil-society groupings are also investigating ocean fertilization. The Ocean Nutrition Foundation[3] has as its mission statement "…to assist the malnourished population of the world by enhancing the production of the oceans and facilitating access to these fish by those most in need", by promoting technology to fertilize open-ocean waters using urea and other ammonia-based fertilizers. The University of Sydney's Ocean Technology Group is also promoting 'Ocean Nourishment' technology as a means of "increasing wild fish stocks and sequestering carbon dioxide from the atmosphere"[4]. A project associated with this programme, in Kenya, proposes a large-scale 'Ocean Nourishment Plant' on the Kenyan coast which will produce urea from natural gas sourced from Saudi Arabia and use it to fertilize ocean waters[5]. Urea fertilization of ocean waters does not yet appear to have been tested on anything but a very small scale, so the true impacts can only be speculated on. The Subsistence Fishing Foundation[6], also associated with the University of Sydney, is also promoting this technology as a way of improving larval fish nutrition and survival, which it is assumed will increase fishery yields (Lu and Lu, 2009). There appears to be no real substantiation that any of these ocean fertilization projects are economically or technically feasible, let alone environmentally or socially acceptable.

[3] http://onf-ocean.org

[4] http://sydney.edu.au/science/usims/ocean_technology/research/nourish.shtml

[5] http://sydney.edu.au/science/usims/ocean_technology/research/kenya.shtml

[6] http://www.subsistencefishingfoundation.org

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ABBREVIATIONS AND ACRONYMS

ABNJ	Areas Beyond National Jurisdiction
AFS	Anti-fouling systems
Ag	silver
As	arsenic
Au	gold
BCE	Before Current Era
BFRs	Brominated flame retardants
CBD	Convention on Biological Diversity
CCS	Carbon capture and storage
Cd	cadmium
CFCs	Chlorofluorocarbons
CH_4	methane
cm	centimetre(s)
Cn	cyanide
CO	carbon monoxide
CO_2	carbon dioxide
dB	decibel
DDT	dichlorodiphenyltrichloroethane
DSL	Deep-scattering layer
ESONET	European Seafloor Observatory Network
FAO	Food and Agriculture Organization (of the United Nations)
Fe	iron
GEF	Global Environment Facility
GESAMP	IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection
GHG	Greenhouse gas
HABs	Harmful algal blooms
HCFCs	Hydro-chlorofluorocarbons
HFCs	Hydrofluorocarbons
Hg	mercury
Hz	hertz
IAEA	International Atomic Energy Agency
IAS	Invasive alien species
IBC	International Bulk Chemical
ICES	International Council for Exploration of the Sea
IMO	International Maritime Organization
IUCN	International Union for Conservation of Nature
kHz	kilohertz
km	kilometre(s)
km^2	square kilometres
LBS	Land-based sources
LOSC	UN Convention on the Law of the Sea
m	metre(s)
mm	millimetre(s)
Mn	manganese
MARPOL	International Convention for the Prevention of Pollution from Ships
MSR	Marine scientific research
N_2O	nitrous oxide
Ni	nickel
NLS	Noxious liquid substances
nm	nautical miles
NOx	nitrogen oxides
OOA	Open-ocean aquaculture
OTEC	Ocean thermal energy conversion
P&I	Protection and Indemnity
PAHs	Polycyclic aromatic hydrocarbons
Pb	lead
PCBs	Polychlorinated biphenyls
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
PFCs	Perfluorocarbons
PFOS	Perfluorooctane sulfonic acid
PFOS-F	Perfluorooctane sulfonyl fluoride
pH	acidity
POPs	Persistent organic pollutants
Pt	platinum
ROVs	Remotely operated vehicles
SF_6	sulphur hexafluoride
SIO	Southern Indian Ocean
SIODFA	Southern Indian Ocean Fishers' Association
Sn	tin
SOx	sulphur oxides
SSGFs	Sub-seabed geological formations
SUA Convention	Convention for the Suppression of Unlawful Acts Against the Safety of Maritime Navigation
TBT	tributyltin
UCH Convention	Underwater Cultural Heritage Convention
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO-IOC	United Nations Educational, Scientific and Cultural Organization – Intergovernmental Oceanic Commission
VOCs	Volatile organic compounds
WHO	World Health Organization
WMO	World Meteorological Organization
Zn	zinc

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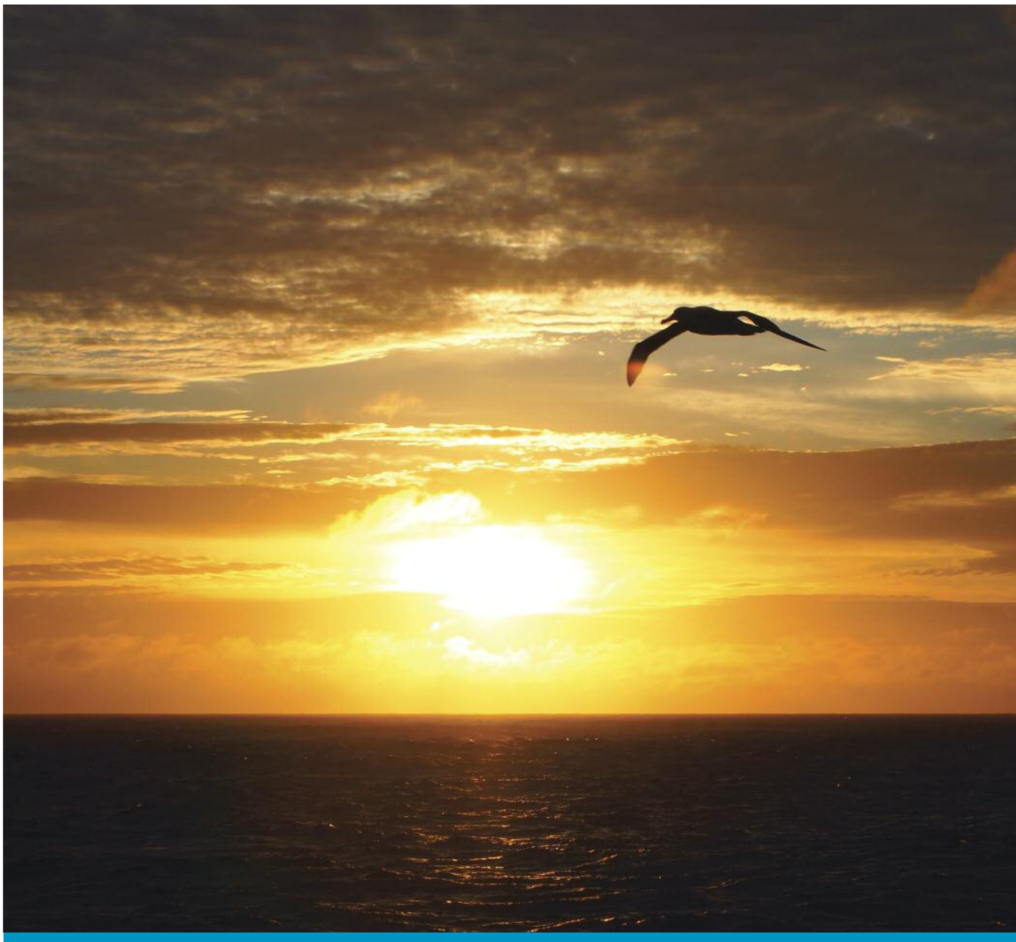

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