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Editorial

Introduction to the special issue: The global state of the ocean; interactions between stresses, impacts and some potential solutions. Synthesis papers from the International Programme on the State of the Ocean 2011 and 2012 workshops

This Special Issue publishes papers on ocean stresses, impacts and solutions that underpinned the findings of workshops hosted by The International Programme on the State of the Ocean (IPSO; http://www.stateoftheocean.org) in partnership with the International Union for the Conservation of Nature (IUCN: http://http://www.iucn.org/).

IPSO was founded to investigate anthropogenic stressors and impacts on the global ocean and to define workable solutions to reduce or eliminate these problems. The distinguishing feature of this programme is that it treats the effects of such stressors collectively, taking a holistic view of marine ecosystems and impacts on them. Recent research has emphasised that to assess the totality of human impacts on the oceans, and the biodiversity it contains, and the resultant negative effects on the goods and services provided by marine ecosystems, the interactions between stresses must be resolved. This is critical because many direct and indirect human stressors act in a cumulative or synergistic fashion. A well-known example of this is the over exploitation of algivorous fish species on coral reefs leading to a decrease in reef resilience, with respect to shocks such as mass coral bleaching, and promoting the phase shift from coral-dominated to algal dominated systems (e.g. Hughes, 1994; Mumby et al., 2006; Hoegh-Guldberg et al., 2007; Hughes et al., 2007). Another example is the increasing recognition of interactions between overfishing and nutrient pollution (eutrophication) in causing cascading changes in marine ecosystems via food-web interactions (e.g. Daskalov, 2002; Daskalov et al., 2007). Climate-change effects, including ocean warming, acidification and hypoxia all potentially interact with each other and with other human impacts including overfishing, pollution and the establishment of invasive species (e.g. Cheung et al., 2010; Johnson et al., 2011; Doney et al., 2012).

Addressing the direct and indirect human impacts on the ocean requires a holistic approach to develop viable and practical approaches to reduce or eliminate current degradation of marine ecosystems. Such approaches must be joined up, for example, the effectiveness of local action to reduce direct human stresses on coral reefs must come with global-level actions to reduce CO_2 emissions. Efforts to reduce fishing mortality to a point where fishing should become sustainable (i.e. below MSY) is of little use if essential fish habitat is eliminated by destructive fishing methods and the resilience of the ecosystem eroded through bycatch of non-target species. Such an approach, which aims to maintain ecosystem health whilst enabling the provision of the goods and services humankind requires, forms the basis for ecosystem-based management (Thrush and Dayton, 2010). It is important to also bear in mind that the oceans are an integral part of the Earth system and as such its functions in maintaining conditions for all life on the planet are critical, a framework first put forward in the Gaia hypothesis (Lovelock, 1979) and elaborated by others (e.g. Schellnhuber, 1999).

In April 2011, and again in 2012, IPSO, in partnership with the International Union for the Conservation of Nature (IUCN), convened workshops at the Margaret Thatcher Conference Centre, Somerville College, University of Oxford. The objectives of the workshops were to:

- Review the latest information on ocean stresses and impacts and the levels of confidence around what is being expressed.
- Summarise the likely consequence of existing stresses on the ocean.
- Summarise the likely consequence of projected stresses from 2020 through to 2050.
- Determine the synergistic effects of multiple stresses on the ocean and what this may mean for the future.
- Consider possible solutions that reduce or eliminate current oceans stresses and impacts and which improve the current trajectory of degradation of marine ecosystems towards a more healthy ocean of the future.

The timeline for consideration was from today through 2020 to 2050.

Obviously addressing problems generated by human impacts on the oceans requires not only scientific input on the nature and cause of the impacts and their likely consequences but also the identification of the socioeconomic drivers of damaging activities and the gaps in management that allow them to take place. An excellent example of this was the recent work on the state of fish stocks on coral reefs in the Indian Ocean that demonstrated a U-shaped or Kuznets-type relationship between the Development Index of States and fish biomass on reefs (i.e. low biomass at intermediate levels of socioeconomic development; Cinner et al., 2009). Communication between the public, users, policymakers and scientists is critical in the development of management strategies to tackle human impacts on the oceans (e.g. Dietz et al., 2003). In many cases, the scientific evidence that marine ecosystems are

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undergoing degradation as a result of human activities is overwhelming. Even where the exact magnitude of impacts and their precise effects are not fully understood there is often enough information available to identify that human activities represent a threat to marine species and ecosystems. The most obvious examples of this relate to the impacts of fisheries on target species (e.g. Rosenberg, 2003), or the impacts of ocean warming on coral reefs through mass bleaching (e.g. Veron et al., 2009). In such circumstances the precautionary principle impels us to take action in mitigation. Yet the public and policymakers fail to recognise human impacts on marine ecosystems, the importance of the consequences of such impacts on ocean goods and services in social and economic terms, and also in terms of a healthy Earth system, or they choose to ignore them. For all of these reasons the IPSO/IUCN workshops drew together experts from a range of different disciplines within marine science, but also from the legal and policy arena and communications specialists from a range of countries.

Through presentations, discussions and recommendations the first workshop in 2011 documented and described the cumulative effects of such impacts, how these commonly act in a negatively synergistic way (Rogers and Laffoley, 2011). Overall it was concluded that the overall risks to the oceans and the ecosystems they support, have been significantly underestimated and that the whole of marine degradation is greater than the sum of its parts and is now happening at a much faster rate than predicted previously. To maintain the goods and services the ocean has provided to humankind for millennia demands change in how we view, manage, govern and use marine ecosystems. The scale of the stresses on the ocean means that deferring action will increase costs in the future leading to even greater losses of benefits. The second workshop in 2012 focused on solutions to the problems identified in the first and ranged from consideration of practical approaches to reduce direct impacts (e.g. reducing fishing capacity) to large scale reform of the systems of governance and law used to manage the oceans and particularly the high seas. The papers in this volume synthesise the findings of the two meetings. With respect to some of the major impacts on the oceans these include the effects of climate change (Bijma et al., 2013), overfishing (Pitcher and Cheung, 2013) and pollution (Hutchinson et al., 2013) at a global scale. Coral reefs form a focus in Ateweberhan et al. (2013) because they are the most threatened and species rich marine ecosystems and have an overwhelming socioeconomic importance. Solutions to the problems faced in the oceans are also discussed. Here the high seas form one notable focus (Gjerde et al., 2013) because it is a global commons and as such has a unique status in terms of international law and the management of its biotic and abiotic resources.

Bijma et al. (2013) describe three prime effects of climate change referred to as the "deadly trio", ocean warming, ocean acidification and deoxygenation. The reason for the nomination is that evidence indicates that these three phenomena are partially or entirely associated with the majority of the major extinction events in Earth's past (e.g. Erwin, 2006; Veron, 2008a,b; Veron et al., 2009; Barnosky et al., 2011; Harnik et al., 2013). Already these effects are causing geographically wide-ranging shifts in the distribution of species (e.g. Reid et al., 2009), episodes of large-scale mortality of marine organisms (e.g. Chan et al., 2008) and they are reducing available habitat for species (e.g. Stramma et al., 2011). The paper points out that thermal limitations determining the distribution of species and their shifts resulting from ocean warming are related to organism oxygen supply and demand, and that there are complex interactions between all three physical manifestations of climate change and physiological response (Pörtner and Farrell, 2008; Pörtner, 2010). Species-level responses cascade through marine ecosystems impacting on ocean biogeochemical pathways through altering marine food webs and the biological carbon pump. Physical processes such as increased stratification in low to middle latitudes will likewise alter global patterns of marine primary production (e.g. Steinacher et al., 2010) with wide spread consequences for marine life and also for the productivity of the oceans from a human perspective. The effects of ocean acidification are also discussed with potential impacts, such as reduced calcification or erosion of calcium carbonate structures such as shells, already being detected in the ocean (Bednaršek et al., 2012). Other effects such as impacts on photosynthetic organisms, influences on oxygen exchange, nitrogen fixation, species reproduction and navigation are less well known. The occurrence of hypoxia or anoxia in marine ecosystems is becoming more frequent and is associated with climate change impacts or a combination of these and other human impacts such as eutrophication (Doney, 2010; Hoegh-Guldberg and Bruno, 2010), and these are also described.

The problem of overexploitation of marine ecosystems is addressed in Pitcher and Cheung. They point out that despite recent analyses that have claimed that fisheries "have turned the corner" (e.g. Worm and Branch, 2012), consideration of fisheries globally suggests otherwise. Overexploitation and depletion of fish stocks is continuing (e.g. Costello et al., 2012; Watson et al., 2012) and together with other human impacts such as ocean warming, acidification and pollution pose a major threat to an important source of human food security and economic activity. Overfishing and destructive fishing practices are also a significant threat to marine biodiversity and ecosystem structure and to date represent the most important cause of extinction and decline in marine ecosystems (e.g. Dulvy et al., 2003). The root cause of these problems are described and clearly lie within inadequate management of fisheries, particularly in the developing world, the very place where climate change impacts are likely to be greatest. Pitcher and Cheung put forward the argument that rather than aiming for the gold standard of full stock assessment alternative methods are required that are less data intensive but which can be employed in parts of the world and in States where the infrastructure and finances do not exist for comprehensive fisheries science. Approaches using MSY coupled with a resilience parameter for the species in question can be effective (e.g. Froese and Martell, 2012). Protection of biodiversity can be achieved through application of ecosystem-based management principles aimed at maintaining not only target fish stocks but also other species dependent on those same stocks and on the ecosystems within which they occur. Such approaches include the use of marine protected areas which have been repeatedly shown to enhance the abundance, biomass and diversity of ecosystems as a result of protection from fishing, as well as a wider range of benefits both for humankind and for nature (Angulo-Valdés and Hatcher, 2010; Fox et al., 2012).

Hutchinson et al. (2013) describe the importance of chemical contamination and pollution of the marine environment, in a reminder that this problem has not receded. As well as the existence of so called "legacy" contaminants such as heavy metals and persistent organic pollutants there are also many emerging chemical contaminants and biotoxins. These latter chemicals include brominated flame retardents, microplastics, nanomaterials, recreational drugs and a variety of other substances (see Hutchinson et al., 2013, and references therein). Thus marine ecosystems are now faced with a "cocktail" of chemical contaminants that potentially may cause harmful effects to marine species and additionally pose a threat to human health via the food chain. The challenges posed by chemical contamination and pollution can be met by initiating a programme of exposure assessments for priority chemicals, establishing a better understanding of the distribution of biological effects of such chemicals and to better understand the impacts of complex mixtures of substances on physiology. The economic and infrastructural challenges posed by such a wide variety of chemicals means that an effects-based strategy will be required.

Atweberhan et al. revisit the threats to coral reefs, a topic that was addressed by a previous IPSO meeting (see Veron et al., 2009). Coral reefs are singled out as an ecosystem that is probably under more immediate threat from human impacts than any other. More so than other ecosystems, the interactions between indirect and direct human impacts have been demonstrated through observation and experiment (e.g. Hoegh-Guldberg et al., 2007). Atweberhan et al. describe the impacts of ocean warming and acidification on reef-forming Scleractinia and also on other reef-associated groups such as soft corals, fish and non-calcareous algae. These effects interact with overfishing, eutrophication, other forms of pollution and also alteration of coastal areas through development and dredging. Almost all of these direct impacts are still increasing in many parts of the world where coral reefs exist (Ateweberhan et al., 2013, and references therein). Most of these impacts interact with climate change impacts leading to an overall effect that is a sum of individual stressors or synergistic interactions. Whilst effects of climate change on the reef-forming corals themselves are well explored, and continue to be investigated, responses of other parts of reef ecosystems are less understood. Soft corals appear to be less susceptible to climate change effects whilst ocean acidification is likely to influence the behaviour of reef fishes with as yet uncertain consequences. Non-calcifying algae are likely to benefit from increased CO_2 and higher temperatures and so may increase the susceptibility of reefs to phase changes. There are hopes that reef-forming corals and their symbionts will adapt to climate change effects but the current rate of climate change (see Bijma et al., 2013) is unprecendented and so such optimism may be unfounded. Regardless, it is critical to reduce other direct impacts on coral reefs, and overall what is required is concerted global action to conserve coral reef ecosystems at local, regional and global scales.

The final paper by Gjerde et al. (2013) addresses ocean ecosystems beyond national jurisdiction, the so called high seas. This area is referred to as the "common heritage of humankind" but its living resources are exploited by vessels from developed States and it is also subject to global problems of climate change, pollution and also large-scale human activities such as shipping. The entire area may be regarded as a frontier and there are signs that other forms of exploitation are approaching a stage where technology and economic conditions may allow them to develop rapidly, a prime example being deep-sea mining. The high seas host some extremely valuable fish stocks, most notably of tunas and billfishes, but also species that have a much lower abundance and are distributed on fragile ecosystems such as seamounts. They have suffered from the lack of management described in Pitcher and Cheung despite legal obligations of States to sustainably manage fish stocks and to conserve associated species and ecosystems. The technology now exists to implement effective monitoring, control and surveillance of fishing activities in the oceans and so an inability to manage fisheries on the high seas comes down to gaps in governance and ineffectiveness of the organisations charged with managing such fisheries. Gjerde et al. (2013) outline possible solutions for addressing gaps in ocean governance as well as implementation of effective measures to control fishing. These range from soft options, such as gaining further resolutions from the United Nations General Assembly to promote better fisheries management, to regional strengthening of management organisations and rules. However, the most ambitious suggestion relates to the establishment of a new UN body charged with ensuring the high seas are managed sustainably which reports to the UN General Secretary and which coordinates all UN bodies in establishing better management of the biotic resources of the high seas.

1. Concluding remarks

It is clear that human activities have led to intense multiple stressors acting together in many marine ecosystems. Most notably these are arising from overexploitation of biotic resources, climate change effects forming the so-called "deadly trio" (ocean warming, acidification and hypoxia/anoxia) and pollution. The "deadly trio" are associated with past extinction events but anthropogenic pollution and resource overexploitation are obviously new phenomena so in the present the oceans are influenced by a unique set of stressors. Such stressors often interact in an additive or negatively synergistic manner meaning that the combination of two or more stresses magnifies the sum of each one occurring alone. This is already resulting in changes in the ocean in all regions, at an increasing rate, and in some cases has resulted in ecosystem collapse. Here we define collapse to indicate a system that has become extensively simplified in physical and biological structure, where significant losses in biodiversity and/or reductions in mean trophic level and/or resilience have taken place, so reducing ecosystem goods and services to humankind now and/or in the future. It is also important to recognise that the changes in the ocean that are coming about as a result of human CO_2 emissions are perhaps the most significant to the Earth system as they involve many feedbacks that will accelerate climate change. For example, changes in ocean stratification have a direct impact on primary production and the biological carbon pump, feeding back to the rate at which CO_2 is absorbed from the atmosphere into the deep sea.

The continued expansion in global population exerts ever increasing pressures on scarcer ocean resources through overexploitation and on marine ecosystems through indirect impacts such as pollution. It is therefore important to recognise that growing impacts on the ocean are inseparable from the population growth and per-capita resource use, and tackling these issues underlies the reduction of the footprint of humankind on all ecosystems. Human interactions with the ocean must change with the rapid adoption of a holistic approach to sustainable management of all activities that impinge on marine ecosystems. The papers and report arising from the IPSO meetings outline some of the important steps towards such a holistic ecosystem-based management approach. Ultimately, however, this has to be part of a wider re-evaluation of the core values of human society and its relationship to the natural world and the resources on which we all rely.

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