greatly improve exploitation of these data. In addition, more free and open-source pre-processing and analysis tools would boost the usage and exploitation of the data beyond a relatively small group of experts. This would stimulate capacity building in developing countries so that they can focus on continuous improvement, with better use of SAR data to complement their optical monitoring systems.

More integrated optical and SAR groups and closer cooperation between research teams is needed to exploit the full potential of SAR-optical remote sensing and to address the arising technical challenges. Recognizing the importance of the Landsat science team for the success of Landsat, and the Kyoto and Carbon Initiative for the progress of L-band SAR applications, a joint science team of optical and SAR experts would clearly be beneficial to extending optical and SAR-based processing and analysis.

Big-data-related issues also need to be addressed. The large and increasing quantity of optical and SAR data requires a shift from downloading of data for local storage and processing, to centralized storage and remote processing of the data on large servers and high-performance facilities. Data infrastructures are required to host and process large volumes of time-series data from several sensors. For example, it may be possible to capitalize on Australian and NASA data cubes or the European Space Agency's thematic exploitation platforms.

Funding opportunities for multi-sensor research beyond mission and country-specific programmes are needed to stimulate priority technical research. Space agencies and other research and development organizations are encouraged to issue more dedicated open calls for proposals that address operationalization of multi-sensor approaches and international partnerships.

The alignment of optical and SAR data for forest monitoring requires a willingness by the two communities to work together and advance algorithms for forest cover change detection that go beyond what can be achieved using either dataset alone. The development and implementation of such algorithms in an open-source environment and based on centralized high-performance computing can be realized with investment and by champions in relevant fields. Realizing these monitoring opportunities would underpin policies to reduce forest loss and provide an improved chance of achieving long-term conservation and sustainable use of forests. ❒

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COMMENTARY:

Intact ecosystems provide best defence against climate change

Tara G. Martin and James E. M. Watson

Humans are adapting to climate change, but often in ways that further compound our effects on nature, and in turn the impact of climate change on us.

Climate change is affecting people and nature across every continent and ocean[1]. Changes in rainfall, snow and ice melt are impacting water resources in terms of quality and quantity. Drought, crop failure and poor yield, and human heat-related stress and mortality are increasing in frequency. Sea-level rise is displacing coastal and island communities through storm surges and saltwater incursion, and deglaciation and range shifts of species on land and sea are leading to loss of ecosystems and creation of new and different ecological communities.

Table 1 | Examples of different human responses to pressures caused by climate change impacting natural ecosystems and their potential negative (bold) and positive long-term consequences.

	Different responses to climate pressure	Possible long-term consequences for local human communities
Erosion from sea-level rise and storm surges	**Destruction of coral reefs to build seawalls[2]**	**Loss of fisheries, loss of storm protection provided by functioning coral reef, loss of tourism and other livelihoods[17,19]**
	Coastal ecosystem (mangrove, salt marsh, estuary) protection and restoration[17,19]	Protection and restoration of a range of ecosystem services and goods with high economic value[17,19]
Increased seasonal variability	**Shifting large-scale agriculture to forested areas[3], over-reliance on crops with low tolerance for climate variability, that is, corn and soybeans[23]**	**Loss of intact native vegetation and the hazard protection it provides[3,12], lost carbon sequestration[9], change in local climate regulation leading to more extreme weather issues[8]**
	Adoption of ecologically sustainable agriculture practices such as agroforestry[24,25]	Increased crop resilience to climate change and increased yields[25]
Increased severity of drought	**Plant breeding and genetic modification for drought-tolerant pastures and crops[5]**	**Development of the next generation of invasive plant species[5]**
	Utilizing plant taxa where the risk of invading natural areas is low[5]	Increased food security with low risk of invasion[5]

In response, many local communities around the world are rapidly adjusting their livelihood practices to cope with climate change, sometimes with catastrophic implications for nature. In low-lying islands across Melanesia, the construction of seawalls out of coral by island communities hoping to slow down the impact of sea-level rise has led to the wholesale destruction of some of the most biodiverse and protein-productive coral reefs in the world[2]. Across the Albertine Rift and valleys of the Congo Basin, farming communities responding to increasingly variable rainfall regimes are expanding their agricultural activities into intact forested systems, threatening the most biologically rich regions in Africa[3]. Throughout the Canadian prairies and Australian grassy woodlands, community pressure following record-breaking dry conditions has led to new government policy allowing ranchers to graze livestock on conservation lands during droughts[4], endangering the resources on which many threatened native species depend. Agricultural industries are also adapting by developing new pasture and crop varieties that are resistant to drought and climate variability[5]. Unfortunately, the same traits that make a plant species successful under climate change are also typical of invasive species. By introducing new genetic and endophyte variation, there is a substantial risk of engineering the next wave of environmental weeds[5]. In the north, sea-ice melt is opening up the Arctic — a region rich in oil and gas — for mining, and at the current rate of melt, a new trans-Arctic shipping route linking the Atlantic and Pacific oceans is predicted by mid-century[6]. These activities not only intensify impacts on polar biodiversity and communities in a region already under severe threat from climate change[7], but will also increase the amount of greenhouse gas emissions into the atmosphere. These are just a few of the human responses to climate change that, if left unchallenged, may leave us worse off in the future due to their impacts on nature.

Natural systems

The role of intact, functioning ecosystems in sequestering vast amounts of carbon is well recognized and has led to initiatives to reduce carbon emissions from deforestation and degradation (for example, REDD+ (Reducing Emissions from Deforestation and Forest Degradation)) as well protection of carbon stores from coastal and marine ecosystems. What has received less attention is the role of natural systems in regulating local climate regimes[8] and reducing risks associated with climate related hazards, such as floods, sea-level rise and cyclones[9]. The degradation of these intact ecosystems affects not only the resilience of biodiversity to climate change[10], but also the significant protection these ecosystems afford from climate-related hazards. When functioning and intact, forests, grasslands, wetlands and coral reefs represent our greatest protection against floods and storms[9,11,12]. Coral reefs can reduce wave energy by an average of 97%, providing a more cost-effective defence from storm surges than engineered structures[11]. Likewise, coastal ecosystems such as mangroves and tidal marshes are proving to be a more sustainable, cost-effective and ecologically sound alternative for buffering storms than conventional coastal engineering solutions[13]. On land, intact native forests have been shown to reduce the frequency and severity of floods[12]. With over 100 million people per year at risk from increasing floods and tropical cyclones[14], ill-conceived adaptation measures that destroy the ecosystems that offer our most effective and inexpensive line of defence must be avoided[2,9].

Thoughtful policy is urgently needed to ensure adaptation leads us in the right direction, and away from perverse outcomes that exacerbate our current environmental and climate crisis. The role of natural ecosystems in sustaining the complex processes that underpin critical regional- and planetary-scale functions is clear[1]. What is also now evident is their role in protecting human societies from future climate change through their intrinsic ability to ameliorate the impacts of global climate change via both the large amounts of carbon they store and their ability to buffer and regulate local climate regimes[8,9].

Ecosystem-sensitive adaptation

Fortunately, adaptation strategies are being developed that do not destroy nature, some of which are even ecosystem-based (Table 1). Ecosystem-based adaptation harnesses the capacity of nature to buffer human communities against the adverse impacts of climate change through the delivery of ecosystem services[15]. The protection and restoration of mangrove forests is a prime example. Mangrove forests protect coastal and island communities from storm surges, tsunamis and sea-level rise, as well as provide ecosystem goods such as food, timber and medicine[16]. Analyses of the cost–benefit of mangrove restoration projects illustrate that rehabilitation can provide net economic benefit even without considering the value of shoreline protection[17]. In fact, mangrove restoration can be more cost effective than installing and maintaining engineered structures. For example, in Vietnam, the cost of planting 12,000 ha of mangroves was $1.1 million, but saved approximately $7.3 million per year in dyke maintenance[18].

In another example, the devastation caused by Hurricane Katrina sparked a debate about the role of salt marshes in attenuating wave energy. Subsequent meta-analyses have confirmed that salt marsh vegetation has a significant positive effect on wave attenuation and shoreline stabilization[19]. Restoration of salt marshes is also orders of magnitude less expensive than engineered solutions for coastal defence, and offers far more flexibility[15].

The cost of adaptation to climate change is likely to be between $US70 and 100 billion per year[20] in the coming decades and commitment from the world's leading G20 economies will be required to support less financially endowed nations. On face value, this may seem a lot, but if we consider another perverse mechanism contributing to climate change, fossil fuel subsidies, it is small change. A recent report by the International Monetary Fund estimates global energy subsidies for 2015 at $US5.3 trillion per year, or approximately $US1,000 for every citizen living in the G20 group[21]. The majority of this comes from countries setting energy taxes below levels that reflect the environmental and health damage associated with fossil fuel energy consumption. Eliminating fossil fuel subsidies would slash global carbon emissions by 20% and raise government revenue by US$2.9 trillion (3.6% of global gross domestic product) — well over the funds needed for intelligent policy and action on climate adaptation[21]. In choosing among potential adaptation strategies, the cost of eroding our natural capital must be part of the decision process[22] and adaptation strategies that do not degrade the protective measures of nature must be a priority. If we lose intact, functioning ecosystems, which are our most cost-effective defence against climate change, the human and financial cost of climate adaptation will be magnitudes higher.

Humans and nature form a coupled system and understanding the feedback between the way we as humans adapt to climate change under different policy agendas and its impact on nature is crucial to successful adaptation. Environmental outcomes and climate outcomes are inextricably linked. It is time to set a policy agenda that actively rewards those countries, industries and entrepreneurs who develop ecosystem-sensitive adaptation strategies. ❐

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