Wicked Problems, Dynamic Solutions: The Ecosystem Approach and Systems Thinking

This sourcebook accompanies the Massive Open Online Course (MOOC) on the Ecosystem Approach and Systems Thinking (EAST) developed by the Loyola Sustainability Research Centre at Concordia University, Montreal, and the United Nations Environment Programme (UNEP) in Nairobi, Kenya. The sourcebook is written for both teacher and student, though it is assumed that most of its readers will be teachers who are applying the MOOC to a hybrid class (blended learning) or are offering the MOOC to students and/or professionals in various branches of public administration, civil society, or the private sector. Each module is described in terms of the main learning objectives, a short introduction to the topic, a summary of prevalent policy initiatives and interventions, a list of suggested "discussion points" that can guide classroom or online discussions/debates, an annotated bibliography of some key sources that have been suggested by our subject experts, and a list of exciting websites, TED talks, and other Internet material that students can easily access for more information. A premium is put on brevity in this sourcebook: each module is dealt with in under fifteen pages. The actual MOOC contains far more material, including visual aids to the concepts and case study material. Each module is designed to take roughly four hours to complete for students in the MOOC; reading each module's section in the sourcebook should take considerably less time. We have also refrained from including images, graphs, and other infographics in the sourcebook, since they are prominent features in the MOOC itself.

We've divided the course into three sections: the first introduces key concepts, the second covers key sectors involved in sustainability and conservation, the third uses cross-cutting issues to demonstrate the utility of the ecosystem approach. Each section should take roughly the same amount of time to complete; teachers can choose, however, to emphasize one over the others if that is their preference. We made conscious choices about which ecosystems to cover in depth, hoping that students can relate our choices to their daily lives. For example, we do not cover mountain, desert, or polar ecosystems except in passing. However, the basic principals of the ecosystem approach, and the need for sustained systems thinking, applies to all the earth's ecosystems and, as importantly, all its human inhabitants.

The main thrust of this course is that we can all benefit from adopting systems thinking in our daily lives and that the environmental problems we face today demand this. The UN Convention on Biological Diversity adopted the ecosystem approach as early as 2000, and it remains central to efforts in biodiversity conservation but also for many other sectors, from forestry to water, where ecosystem services are threatened by land use conversion, invasive species, pollution, climate change, and other factors. Key to the evolution of the ecosystem approach is the purposeful involvement of the human dimension in decision-making, and we devote one of the introductory modules to this theme. The team that put this MOOC together have both natural and social science backgrounds, which we hope is reflected in the material here. This clear insistence on the human dimensions of the ecosystem approach lead to some unusual components of the course: for example, we include a specific module on human public health concerns, compiled with help from EcoHealth Alliance in New York City. Our intention is to demonstrate to students that the ecosystem approach and systems thinking can be used in various contexts and across disciplinary and sectoral divides for shared benefits. This is a deliberate effort to mainstream environmental issues and promote a transdisciplinary methodology in the process.

Though we hope this sourcebook and the related MOOC will be distributed and used as an educational resource as widely as possible, we are particularly pleased that they are both intimately related to the Global Universities Partnership on Environment and Sustainability, one of UNEP's flagship programmes. GUPES is a network of close to 800 universities that integrates environmental concerns into teaching, research, and adult education. GUPES also seeks to lead the greening of university infrastructure, facilities and operations, and to enhance student engagement and participation. We hope this network can take advantage of this material as a supplement to educational programmes offered across the world.

The Advanced Certificate

There are 10 modules in this MOOC, each of which is summarized in this sourcebook. However, we have also added an advanced certificate option for this course through Module 11, which gives students a chance to engage in more detailed, demanding study. Specifically, we ask them to design a response to a wicked problem that affects their own lives, whether it is an ecological challenge to community survival, a public policy dilemma in their home country, or broader concerns about global biodiversity conservation or other issues. In a blended course, they can do this on an individual basis or in teams, compiling a five-minute video that will be uploaded onto the site and perhaps posted for broader public consumption on social media, and a 3,000-3,500-word paper outlining their problem and solutions. Unlike the 10 modules outlined here, which will be automatically graded on a pass/fail basis, the Advanced Certificate work will be graded by the teaching team for the course if it is taken as part of a blended learning experience, and we will use peer-review grading for those students taking the course purely online. It is expected that few of the students registered in this course will go on to complete the Advanced Certificate because it will be highly demanding and require at least another 20 hours of work and substantial time collaborating with team-mates. Please see the last chapter in this sourcebook for more information on completing the Advanced Certificate, which can also be used in a blended classroom as the major assignment for the term.

Please note that comments/corrections/suggestions on this Sourcebook are very welcome. Please address them to Dr. Peter Stoett: peter.stoett@concordia.ca.

Dr. Stoett is grateful to the many contributors to the UNEP EAST MOOC project. Since there is considerable overlap with contributors (from Concordia University, UNEP, and Knowledge One) we name them only in the MOOC itself.

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Module 1: Systems Thinking

Expected Learning Outcomes: upon completion of this module, students will be able to

- distinguish between closed and open, and simple and complex, systems
- distinguish between reductionist and complex approaches to problem solving
- distinguish between a simple and wicked problem
- understand why a reductionist approach is not appropriate to address a wicked problem
- identify the basic characteristics of complex adaptive systems, including emergent properties, path-dependency, feedback loops, and others
- understand and explain the concept of resilience
- realize that human perception is an important part of adaptive management
- understand that technological advances can help us to understand complex adaptive systems and approach the world from a systems thinking perspective, but also be able to identify limitations of these technologies

An Introduction to Systems Thinking

What does it mean to take a **systems approach** to complex problems? A system is defined as a set of interacting components that interact to form a whole. Examining the system by observing the component parts is generally referred to as a reductionist approach. A systems approach, in contrast, implies that we need to think in terms of the whole, while paying attention also to the parts of the system and how they interact with each other (Waltner-Toews et al. 2008). And since systems exist within a broader universe of other, interacting systems, we also need to "zoom out" to see the larger picture. Interestingly, many human made systems mimic natural systems already, and we are learning how to take advantage of "biomimicry" in our systems designs and engineering feats. But we don't often apply a systems approach to the problems we face in everyday life, or for that matter the "wicked problems" related to environmental issues that we need to solve in collective fashion.

Systems can be open or closed. A closed system requires no input from outside, which is rare outside the world of chemistry and thermodynamics. Most systems are open, in that they require and are constantly influenced by input from outside and also produce some output which affects the broader environment around them. As we will learn in this course, ecosystems are excellent examples of complex, open systems on which we all rely for our survival. But we need also to define **system boundaries** – what components of nature exist inside and outside (the broader environment) in order to grasp where one system begins and another ends.

A **simple system** is one made up of linear interactions between system components that result in a predictable outcome. An automobile is a simple system: if nothing is broken, and the car has sufficient fuel, the driver puts it in gear, presses the accelerator, and predictably, the car moves. If this doesn't happen, it is generally fairly easy to figure out which component is broken and fix it so that the system will function again. The car is also an open system: the driver comes from outside the system, as does the fuel it uses to work, and emissions are the environmental output. (It worth adding that if we consider the entire production chain of the car here, it becomes a very complex system involving oil extraction or battery design, the production of parts in many different locations, labor relations, market forces and advertising – and the laborious process of dispensing with the car after its product life cycle has expired!)

Feedback loops are integral to the dynamics of systems. Even simple systems are regulated by feedback loops: if a car engine is given more fuel, the pistons move faster and burn additional energy, which leads to the car moving faster (and increases the output of emissions). To maintain a specific constant speed, continuous adjustments must be made to account for slopes, differences in pavement, road conditions, etc. A feedback loop consists of the information by which the system adjusts itself. For example, a car will slow down going uphill if the amount of fuel fed to the engine is constant. This information ("the vehicle is slowing down") will be received by either the driver or the car's autopilot, and the amount of fuel used will be purposefully increased, in turn maintaining or increasing the speed of movement. If this correction exceeds the amount necessary to maintain a given speed, this information becomes another feedback loop, which may lead to yet another correction: reducing fuel intake. Systems thus tend to oscillate in response to feedback loops. They can be relatively stable, but this is best conceived as a dynamic stability rather than a static one. Your body is a great example: it is constantly adjusting to feedback in the environment around you, yet you would probably not think of yourself as an unstable entity (at least, not in the physical sense).

These dynamics entail the possibility of a "runaway" situation. This happens when feedback loops are either not perceived, or when they are perceived but there is no response. In order to maintain a given constant speed going downhill, a vehicle that needed heavy fuel input going uphill needs to have the brakes applied instead. However, if the driver is distracted or the autopilot malfunctions such that it does not take the increasing speed into account, the car may accelerate to a point where neither the driver nor the autopilot can control it, leading to a crash. We will see later in this module that 'runaways' can threaten the survival of systems once **tipping points** are reached.

A complex adaptive system is also composed of interactions between system components, but the interactions may occur over multiple spatial and temporal scales and are such that the overall outcome is not easily predicted. A **complex adaptive system** is one in which complexity emerges from a small set of critical processes that create and maintain the self-organizing properties of the system's interacting components such that even if some parts are lost/damaged the system as a whole may continue to exist (Holling 2001). Complex adaptive systems are said to have memory: how they change and adapt will be shaped by their initial state and by the disturbances they have undergone. A complex system is not necessarily complicated in that it is often composed of simple interactions and simple rules regulating relationships between interacting components; examples from the natural world include flocks of birds, schools of fish, and herds of ungulates. Again, the whole system is greater than the sum of all its parts (think of a musical symphony, where the instruments interact with each other to produce the music). In the case of flocking, schooling, and herding, at the scale of the individual animals (the components of the system), the system is regulated by three simple rules that all the animals instinctively follow, without which there would be complete chaos:

(1) they maintain a certain amount of *separation* or distance from their nearest neighbours to avoid collision,
(2) they aim to maintain the same velocity as the nearest neighbours (*velocity matching*), and
(3) they aim to stay close to their nearest neighbours (*flock centering*) (from Reynolds 1987).

Even when these system rules are followed, the overall result can be extremely difficult to predict, despite advances in complex modeling in recent years. While we can often ***identify*** the main structural rules that define a system, it is more difficult to ***predict*** outcomes of the collective behavior of its components, even when they follow the rules with relative rigidity.

A forest is an example of a complex adaptive ecosystem. Although we know that trees need light, water, and nutrients to grow, that they may compete with each other for these resources, that their seeds may be propagated by the wind, mammals and birds, and that the uptake of soil nutrients may be facilitated by fungi that interact in a symbiotic way with roots, we cannot predict the exact species composition of the stand or structure of the trees, when they will die, when and which new ones will grow, etc. A forest also adapts to changes in conditions. For example, if there is an outbreak of a certain insect pest that only strikes one species, over time, the forest will change to have less of these susceptible trees. Another example is that of fields or forests whose plants have developed, presumably through random mutation, the ability to respond to the attack of insect herbivores by releasing chemicals that attract the natural predators of these insects (for example, when attacked by herbivores such as the hawkmoth larva, wild tobacco plants release volatile organic compounds that attract predatory insects; see Kessler & Baldwin 2001).

Complex adaptive systems are characterized by **emergent properties** and **self-organization** as well as by **indeterminacy and path-dependency**:

- Emergent properties are those that arise when components of a system are put together; they cannot be soundly predicted by our knowledge of the behavior of individual components (Novikoff 1945).
- Self-organization is a process through which some form of overall order or coordination arises out of the local interactions between the components of an initially disordered system. This process of self-organization is not necessarily controlled by any external agent; although it may be affected by external agents, it is often triggered by random fluctuations that are amplified by feedbacks. The resulting organization is wholly decentralized or distributed over all the components of the system. As such, the organization is typically robust and able to survive and even self-repair.
- Indeterminacy refers to the inherent uncertainty of an event.
- Path dependence is the phenomenon of some interactions being dependent on other

interactions having occurred in a specific way earlier or at a smaller spatial scale. All these concepts will be used throughout this course to illustrate the complexities of the ecosystem approach.

The extent to which a system can adapt while maintaining its fundamental functions is referred to as **resilience**. Resilience is also defined as "the magnitude of disturbance that can be absorbed or accommodated before the system changes its structure by changing the variables and processes that control system behaviour" (Holling & Meffe 1996:330). This is distinct from simple resistance to external shocks. **Resistance** is best defined as "the capacity of an ecosystem to withstand the impacts of drivers without displacement from its present state" (Millenium Ecosystem Assessment). To return to the example of an invasion of pests in a forest, despite changes in species composition, the maintenance of fundamental system properties (its value as a source of habitat, a set of key relationships between species like fungi, bacteria, trees, timber, recreational opportunities, etc.), means it has demonstrated its resilience. In contrast, if the trees of a susceptible species were able to withstand an invasion of pests, and therefore this insect outbreak did not lead to adaptation, the forest would be said to be resistant.

Flexibility, adaptation, and scale are all crucial to the concept of resilience. Holling's idea of adaptive cycles is useful here to illustrate how incorporating small-scale crises that allow for reorganization leads to resilience, and how cycles of **panarchy** (the co-existence of stability and change) interact between spatial and temporal scales. Forest fires present a good example: both natural and human-induced (anthropogenic) fires have the traits of flexible adaptation. Historically, for example, indigenous people practiced controlled fire management to obtain important ecological benefits such as getting certain types of seeds to germinate, maintaining grassland resilience, and even health dynamics within the species that comprise a forest (see http://www.pacificbio.org/initiatives/fire/fire_ecology.html and http://www.freshfromflorida.com/Divisions-Offices/Florida-Forest-Service/Wildland-Fire/Prescribed-Fire/The-Natural-Role-of-Fire). Of course, the impact of fires can be both beneficial and problematic for certain species within the forest ecosystem. But overall the resilience of the system will be demonstrated as it adapts to this increasingly frequent large-scale event.

Simple vs. "wicked" problems

Wicked problems are central to this course so it is important to distinguish them from simple problems. Basically simple systems have simple problems. If an automobile doesn't run when the accelerator is pressed, it may be related to inadequate fuel supply. The problem of an empty gas tank or dead battery would have a simple solution: fill it up the gas tank with petrol, or recharge the battery. If the car still does not run, some other component might have to be fixed or replaced, but the solution would then also be simple: fix the broken component. On the other hand, complex adaptive systems are often plagued by what are termed wicked problems. ***A wicked problem is one "with no definitive formulation, no stopping rule, and no test for a solution", one that cannot be separated from issues of values, equity and social justice (Berkes 2004:624).***

We should note that simple systems can fail due to the concurrence of various simple problems: once compounded, they become wicked problems themselves. The space shuttle Challenger accident in the 1980s is an example of multiple system failure that included a technological failure (the conditions that lead to the explosion of the tank) and failure in human communication (a serious warning by an expert was ignored).

A simple, reductionist approach (which focuses on the individual components of a system only) will not work to solve a wicked problem. A systems-thinking approach is necessary. For example, we can't help society cope with substance addiction without looking beyond the characteristics of addicted individuals and substances (such as alcohol, prescription or illicit drugs) involved. There is a much broader constellation of factors, some at the societal level and some at the metabolic level, that lead to substance addiction, and how we see those factors will to some degree determine our attitudes toward various possible interventions. Indeed, it is very important that we are aware of the added complexity of the human element when it comes to attempting to solve wicked problems. We are both blessed and burdened with the element of human perception, reflecting the complexity of our brains and influences from culture, science, philosophy and other conceptual inputs. We will always have an incomplete view of complex adaptive systems due to these contingencies, and though scientific consensus remains our most valuable tool in the advancement of our knowledge, it is also subject to political manipulation and cultural distortion.

Adaptive management is crucial to addressing wicked problems. Adaptive management is a systematic process for continually adjusting policies and practices by learning from the outcome of previously used policies and practices. Each management action is viewed as a scientific experiment designed to test hypotheses and probe the system as a way of learning about it (Holling 1978). The adaptive management cycle includes four stages: (1) planning, (2) carrying out the plan, (3) monitoring, and (4) interpreting the results of the monitoring so that a new, hopefully more appropriate plan can be developed. Learning from experience is key.

Technological advances can also help us understand complex adaptive systems from exciting new perspectives, including system models that are only possible because of the computer power of this century (climate change modeling is a prime example here). New technology is permitting more effective visualization, understanding and management of complex systems. Such capabilities are driven by the use or combined use of sensor webs, interoperability standards, remote observation techniques, open modeling environments, and the emergence of powerful Web-based data tools. Such capabilities lie behind pathbreaking innovations in the assessment of fire risk in North America, the potential spread of invasive species and pathogens, and in novel approaches to monitoring watershed systems through networked sensors coupled with real-time distributed hydrologic models. We return to the theme of technological advances in systems thinking throughout the course.

However, there are no easy answers or solutions to wicked problems, and we do not want to create the false impression that any simple formula can lead to such answers. As we will see throughout this course, the challenges posed by the threats to ecosystem integrity and the biosphere today are particularly daunting. But systems thinking can help us to train ourselves to see the bigger picture when approaching them. To refer to an old parable, we are often warned to avoid missing the forest when looking at the trees, or vice-versa: clearly, we need to see the forest and the trees within it, as well as the broader global context in which the forest is situated.

Case study

Global Food Supply as a Complex Open System

Complex systems are hard to understand and when they fail to provide their intended output, we are faced with wicked problems. Global food supply is an example of this complexity; it is continuously affected by environmental aspects (rainfall, nutrients, climate, pollination), political structures and disturbances (trade agreements, changes in government, violent conflict), and economics (pricing mechanisms, commodity price trends).

According to a UNEP Report launched in May 2016 (http://www.unepfi.org/fileadmin/documents/ERISC_Phase2.pdf), "Higher and more volatile food prices are likely to be one of the main ways through which environmental risks and constraints such as climate change and water scarcity will impact national economies. If these impacts are significant enough, they also have the ability to affect a country's credit rating and the risk exposure of sovereign bondholders. The global food system is particularly vulnerable to changing environmental conditions. Climate change along with land and water scarcities will increasingly affect food production on the supply side. At the same time, demand for food will increase as a result of global population and income growth. The growing imbalance between rising demand levels for food and a capacity to supply it that is limited by environmental constraints and the effects of climate change will lead to greater variability in food production, higher food commodity prices and volatility, and a higher likelihood of important price shifts."

The impact of political factors and the structure of a food supply system that is heavily concentrated in some key countries were demonstrated prior to the Arab Spring protests of 2008. "Concentration of production increases the risks of unilateral actions. During the 2008 Arab Spring crisis over 30 governments imposed export controls, bringing agricultural markets to the edge. In 2011, Russia's export ban on wheat drove up international prices and led to the initial protests in North Africa that became the Arab Spring" (From Resource Futures, Chatham House report). Ecosystem resilience is vital for global food security as well, as we will see throughout this course.

Discussion points

1. Try to imagine yourself as a component in the various systems that make up your daily life (food provision, political and religious institutions, technological systems on which you rely). Could you function in isolation?
2. Then think of the countless interactions with those systems that you have, and how you have an impact on them.
3. Think of the social systems that shape your day, such as your educational institution, from a systems perspective: how it functions with all of its components to form a greater

whole. Are these systems resilient? Are they plagued with wicked problems? Can you see possible solutions? Compare your thoughts with classmates.

Annotated bibliography

Reynolds, C. W. (1987). "Flocks, herds and schools: A distributed behavioral model." *Computer Graphics* 21(4): 25-34. *This is the original paper describing the rules behind flocking, schooling, and herding behavior such as the behavior of the flocks of starlings seem at https://vimeo.com/31158841. This is a good example of a complex adaptive system resulting from simple interactions between components and leading to emergent properties.*

Kessler, A., & Baldwin, I. T. (2001). "Defensive function of herbivore-induced plant volatile emissions in nature." *Science*, 291(5511), 2141-2144. *This paper presents the case of the native tobacco plants that release chemicals to attract predators when they are attacked by herbivores.*

Vester, F. (2012). "The art of interconnected thinking: ideas and tools for a new approach to tackling complexity." BoD–Books on Demand. *This book provides an introduction to complex adaptive systems and systems thinking as well as details on tools to address wicked problems.*

Holling, C.S. (2001). "Understanding the complexity of economic, ecological, and social systems." *Ecosystems* 4: 390-405. *In this widely read paper, Holling presents a working definition of complex adaptive social/economic/ecological systems.*

Novikoff, A. B. (1945). "The concept of integrative levels and biology." *Science* 101(2618): 209-215. *In this paper, Novikoff defines emergent properties and explores the importance of interactions across scales in complex adaptive systems.*

Holling, C. S., & Meffe, G. K. (1996). "Command and control and the pathology of natural resource management." *Conservation Biology* 10(2): 328-337. *In this paper, Holling and Meffe criticize management approaches that seek to control all aspects of complex adaptive natural systems, putting forth the idea that allowing some variation within a system is crucial to its resilience.*

Berkes, F. (2004). "Rethinking community-based conservation." *Conservation Biology* 18(3): 621-630. *This paper focuses on the importance of incorporating humans into our concept of ecosystems, recognizing that the complex adaptive systems we seek to manage and the wicked problems we seek to solve include humans.*

Recommended websites

Videotaped interview of Luke Houghton defining wicked problems: (https://www.youtube.com/watch?v=qUH5XOPF8pc

Steven Nixon on how to solve wicked problems:

https://www.youtube.com/watch?v=qUH5XOPF8pc

There are many videos of flocking, herding, and schooling behavior to be found on sites such as youtube.com. This one of flocking starlings is particularly amazing and illustrates very well the emergent properties typical of a complex adaptive system: https://vimeo.com/31158841

The website of the Resilience Alliance (http://www.resalliance.org/) has a great section on key concepts in systems thinking and resilience (including some very useful videos) and a helpful glossary with references

The Hyogo Framework for disaster reduction shows how the resilience concept has been used elsewhere and has huge international relevance. http://www.unisdr.org/2005/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf

Peter Fryer provides a brief description of complex adaptive systems, suitable for an introductory-level course, at http://www.trojanmice.com/articles/complexadaptivesystems.htm

The Donella Meadows Institute has a list of resources on systems thinking on their website: http://donellameadows.org/systems-thinking-resources/

Ted Wujec discusses wicked problems and the importance of collaborative processes to address these problems in his TED talk on how to make toast, available at https://www.ted.com/talks/tom_wujec_got_a_wicked_problem_first_tell_me_how_you_make_toast

Module 2: Ecosystems and the Ecosystem Approach

Expected Learning Outcomes: upon completion of this module, students will be able to

- understand ecosystems as complex adaptive systems
- describe the ecosystem services framework developed by the Millennium Ecosystem Assessment, and some examples of different services provided by ecosystems

- understand basic dynamics of ecosystems, including examples of thresholds, regime shifts, resilience, path-dependency
- define and describe the ecosystem approach, comparing and contrasting it with other environmental management approaches, based on an equilibrium view of ecosystems

Ecosystems and ecosystem services

Under the United Nations Convention on Biological Diversity (CBD), an ecosystem is defined as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit." This definition stresses function rather than scale: an ecosystem is not defined in terms of its size, but rather by the fact that it is a functional unit. For example, a small log lying on the forest floor that has been colonized by insects, fungi and plants is an ecosystem, and the entire forest in which it is found – perhaps hundreds of square kilometers in size, such as the Amazonian forest -- is also an ecosystem. Ecosystems are not fixed in time and space, but are dynamic ecological units: "[a]n ecosystem is a fluid, changing entity that undergoes various processes, moves energy and materials, and changes over time" (Meffe et al, 2002). And we need to stress the fact that ecosystems include humans (unless they are located in increasingly rare pristine spaces).

For several decades now, scientists have adopted an **ecosystem services framework** (Millennium Ecosystem Assessment) to better understand ecosystems. Many of these services directly benefit us. For example, these functions include trees sequestering carbon and releasing oxygen (see Module 5, Forests), coral reefs and mangroves protecting coastal areas from waves (see module 7, Oceans and Coasts), fish harvested from rivers as food (see module 6 Rivers systems), and pollination by bees and other insects.

The UNEP defines ecosystem services as: "the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth." Target 14 of the CBD's Strategic Plan for Biodiversity is to ensure that "by 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities and the poor and vulnerable." Recent analyses suggest, however, that we are far from achieving this goal; in fact, according to the CBD's flagship publication, the *Global Biodiversity Outlook* of 2014, "…in the case of services of particular importance to local and indigenous communities, women, the poor and vulnerable, trends appear to be moving in the wrong direction."

The ecosystem services framework can also be used to put **financial values** on these services. Estimates have been made in terms of individual ecosystems or in the global context (Costanza et al., 2014; de Groot et al., 2012). (One example is the REDD+ program, discussed in Module 5 on Forests.) This framework can be used to develop incentives for conservation, putting a price tag on environmental destruction that reflects the realities of the conventional model of economic growth. Some environmentalists worry that this approach further commoditises nature, but many ecological economists applaud such efforts since harms to ecosystems have often been viewed as "externalities" in cost-benefit calculations.

The tendency to overlook environmental costs should not be underestimated and is often apparent in the context of development plans. For example, in Nepal, efforts to construct passable roads were undertaken at the local government level without much prior environmental assessment. No doubt, the roads needed work, but since heavy bulldozers were used to level land for road construction, according to the UNEP, the resulting environmental damage was quite pronounced, "including shifting ground, loss of forest cover and substantial pollution. The Ministry of Federal Affairs and Local Development undertook an economic study analysing local government investments in roads and learned that the use of heavy machinery resulted in steep environmental costs compared to more environmentally friendly labour-based technologies" (UNEP brochure, 2016).

In recent decades, a paradigm shift toward "New Ecology" has accompanied our increasing understanding of ecosystems, wherein environmental management is more about managing human (including corporations, institutions and individual) behaviour than "managing" the plants and animals found in nature. Environmental management was initially focused on an equilibrium view – the pursuit of static as opposed to dynamic stability, as discussed in our previous module -- and on controlling variables ("command-and-control" management). This approach was based largely on calculations such as an assessment of the maximum sustainable yield (MSY) of stocks (of wood or fish, for example), and the management of individual species. This perspective assumed that environmental problems were clearly defined, relatively simple, and generally linear with respect to cause and effect. But command-and-control management was problematic as issues arose with the sustainability of agricultural monocultures (the growth of only one species on farms), straightening of rivers (see module 6 on fluvial systems), and the collapse of fisheries, such as the Atlantic cod population off the east coast of Canada.

The widespread recognition that ecosystems are complex adaptive systems changes our perception of how to deal with the challenges of our time. Ecosystems are not stable, pristine entities from which we can inexhaustibly draw our own beneficial resources. They are characterised by thresholds, regime shifts, resilience, leverage points and feedbacks (we covered some of these concepts in Module One and will cover the others soon). Ecosystems are constantly in flux. This leads ecologists to think of the adaptive cycle in ecosystems, based on the work of Gunderson and Holling (2001), who identified four distinct phases:

1. growth or exploitation (r)
2. conservation (K)
3. collapse or release (omega)
4. reorganization (alpha)

The adaptive cycle exhibits two major phases (or transitions). The first, often referred to as the foreloop, from r to K, is the slow, incremental phase of growth and accumulation. The second, referred to as the backloop, from Omega to Alpha, is the rapid phase of reorganization leading to renewal. (source: http://www.resalliance.org/adaptive-cycle).

When several adapted cycles are connected in a "nested hierarchy", we have what has been called **panarchy. "**Two significant connections are labeled 'revolt' and 'remember'. The smaller, faster, nested levels invent, experiment and test, while the larger, slower levels stabilize and conserve accumulated memory of system dynamics. In this way, the slower and larger levels set the conditions within which faster and slower ones function. Thus a forest stand moderates the climate within the stand to narrow the range of temperature variation that the species experience" (source: http://www.resalliance.org/panarchy). Needless to say, this level of complexity changes our thinking about how to deal with the wicked problems associated with cliamte change, resource exploitation, biodiversity loss, poverty, and many other contemporary issues.

The Ecosystem Approach

The ecosystem approach is the primary framework for action under the Convention on Biological Diversity, and the governing body (the "Conference of the Parties") has agreed on this definition:

"The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Application of the ecosystem approach will help to reach a balance of the three objectives of the Convention. It is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems."

We adapt this as our key definition for the ecosystem approach for this course. There are other definitions available, but they all have some common threads, such as the use of ecosystem boundaries (biophysical or ecological boundaries) rather than administrative or political units such as national or municipal borders. The emphasis on systems thinking -- promoting integration across spatial and temporal scales, preferred over reductionist approaches, is perhaps self-evident. Also important is the determination to take a cumulative view (looking at impacts over time) that focuses on sustainability (resilience promoted through adaptive management and governance) and explicitly integrates the human dimension (see Module 3). The approach considers the whole array of ecosystem components (e.g. human activities, habitats and species, and physical processes) and interactions, as well as the services provided by ecosystems. However, this doesn't mean that an ecosystem approach seeks to analyze every single component and linkage within an ecosystem, which would be physically and intellectually impossible in most cases (this is a common misconception); we need to concentrate on what we feel are key elements and the interactions between them.

The CBD explicates 12 "complementary and interlinked" principles of the ecosystem approach and it is important that students understand each of them and apply them to their own thinking throughout this course. They are reprinted here in Box 2.1.

BOX 2.1: The 12 Principles of the Ecosystem Approach

Principle 1:The objectives of management of land, water and living resources are a matter of societal choices. Different sectors of society view ecosystems in terms of their own economic, cultural and society needs. Indigenous peoples and other local communities living on the land are important stakeholders and their rights and interests should be recognized. Both cultural and biological diversity are central components of the ecosystem approach, and management should take this into account. Societal choices should be expressed as clearly as possible. Ecosystems should be managed for their intrinsic values and for the tangible or intangible benefits for humans, in a fair and equitable way.

Principle 2: Management should be decentralized to the lowest appropriate level. Decentralized systems may lead to greater efficiency, effectiveness and equity. Management should involve all stakeholders and balance local interests with the wider public interest. The closer management is to the ecosystem, the greater the responsibility, ownership, accountability, participation, and use of local knowledge.

Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems. Management interventions in ecosystems often have unknown or unpredictable effects on other ecosystems; therefore, possible impacts need careful consideration and analysis. This may require new arrangements or ways of organization for institutions involved in decision-making to make, if necessary, appropriate compromises.

Principle 4: Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should:

a. Reduce those market distortions that adversely affect biological diversity;
b. Align incentives to promote biodiversity conservation and sustainable use;
c. Internalize costs and benefits in the given ecosystem to the extent feasible.

The greatest threat to biological diversity lies in its replacement by alternative systems of land use. This often arises through market distortions, which undervalue natural systems and populations and provide perverse incentives and subsidies to favor the conversion of land to less diverse systems. Often those who benefit from conservation do not pay the costs associated with conservation and, similarly, those who generate environmental costs (e.g. pollution) escape responsibility. Alignment of incentives allows those who control the resource to benefit and ensures that those who generate environmental costs will pay.

Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach. Ecosystem functioning and resilience depends on a dynamic relationship within species, among species and between species and their abiotic environment, as well as the physical and chemical interactions within the environment. The conservation and, where appropriate, restoration of these interactions and processes is of greater significance for the long-term maintenance of biological diversity than simply protection of species.

Principle 6: Ecosystems must be managed within the limits of their functioning. In considering the likelihood or ease of attaining the management objectives, attention should be given to the environmental conditions that limit natural productivity, ecosystem structure, functioning and diversity. The limits to ecosystem functioning may be affected to different degrees by temporary, unpredictable artificially maintained conditions and, accordingly, management should be appropriately cautious.

Principle 7: The ecosystem approach should be undertaken at the appropriate spatial and temporal scales. The approach should be bounded by spatial and temporal scales that are appropriate to the objectives. Boundaries for management will be defined operationally by users, managers, scientists and indigenous and local peoples. Connectivity between areas should be promoted where necessary. The ecosystem approach is based upon the hierarchical nature of biological diversity characterized by the interaction and integration of genes, species and ecosystems.

Principle 8: Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term. Ecosystem processes are characterized by varying temporal scales and lag-effects. This inherently conflicts with the tendency of humans to favour short-term gains and immediate benefits over future ones.

Principle 9: Management must recognize that change is inevitable. Ecosystems change, including species composition and population abundance. Hence, management should adapt to the changes. Apart from their inherent dynamics of change, ecosystems are beset by a complex of uncertainties and potential "surprises" in the human, biological and environmental realms. Traditional disturbance regimes may be important for ecosystem structure and functioning, and may need to be maintained or restored. The ecosystem approach must utilize adaptive management in order to anticipate and cater for such changes and events and should be cautious in making any decision that may foreclose options, but, at the same time, consider mitigating actions to cope with long-term changes such as climate change.

Principle 10: The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity. Biological diversity is critical both for its intrinsic value and because of the key role it plays in providing the ecosystem and other services upon which we all ultimately depend. There has been a tendency in the past to manage components of biological diversity either as protected or non-protected. There is a need for a shift to more flexible situations, where conservation and use are seen in context and the full range of measures is applied in a continuum from strictly protected to human-made ecosystems.

Principle 11: The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices. Information from all sources is critical to arriving at effective ecosystem management strategies. A much better knowledge of ecosystem functions and the impact of human use is desirable. All relevant information from any concerned area should be shared with all stakeholders and actors, taking into account, inter alia, any decision to be taken under Article 8(j) of the Convention on Biological Diversity. Assumptions behind proposed management decisions should be made explicit and checked against available knowledge and views of stakeholders.

Principle 12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines. Most problems of biological-diversity management are complex, with many interactions, side-effects and implications, and therefore should involve the necessary expertise and stakeholders at the local, national, regional and international level, as appropriate.

SOURCE: https://www.cbd.int/ecosystem/principles.shtml

Importantly, an ecosystem approach demands **flexible thinking and adaptive management** and the ability to **respond to feedbacks**. This may entail interagency cooperation amongst governing authorities, or even deep organizational change; and the participation by many stakeholders in consensus-based decision making, rather than command-and-control by a few.

The CBD has developed a sourcebook to guide practitioners, managers, and policy-makers in implementing the ecosystem approach to environmental management, and students are encouraged to read it. It includes an array of guidelines, tools, case-studies and other practical information, and is available online: https://www.cbd.int/ecosystem/sourcebook/default.shtml.
In an attempt to make the key principles more user-friendly, the International Union for the Conservation of Nature (often referred to as the World Conservation Union) developed a Commission on Ecosystem Management which has regrouped the 12 key principles adopted by the CBD under 5 steps, each divided into subcomponents, and arranged them in chronological order (Shepherd, 2008) (see Table 1 below): key stakeholders and area; ecosystem structure, function, and management; economic issues; adaptive management over space; and adaptive management over time. There are other ways to group the principles as well. For example, one could group them according to social justice issues, scientific input, the participation of indigenous peoples, and other categories. The take-away is that the principles encompass a wide range of factors that integrate the human and natural worlds and rely on systems-level thinking and public participation for a broader vision of ecosystem management.

Table 1. The 12 Ecosystem Approach principles, grouped into five steps by IUCN's CEM

Step A. Key stakeholders and area		
Stakeholders	Principle 1 Principle 12	The objectives of management of land, water and living resources are a matter of societal choice. The EA should involve all relevant sectors of society and scientific disciplines.
Area analysis	Principle 7 Principle 11 Principle 12	The EA should be undertaken at the appropriate spatial scale. The EA should consider all forms of relevant information. The EA should involve all relevant sectors of society and scientific disciplines.
Step B. Ecosystem structure, function and management		
Ecosystem structure and function	Principle 5 Principle 6 Principle 10	Conservation of ecosystem structure and function, to maintain ecosystem services, should be a priority. Ecosystems must be managed within the limits of their functioning. The EA should seek the appropriate balance between, and integration of, conservation and use of biological diversity.
Ecosystem management	Principle 2	Management should be decentralized to the lowest appropriate level.
Step C. Economic issues		
	Principle 4	There is usually a need to understand and manage the ecosystem in an economic context and to: i) reduce market distortions that adversely affect biological diversity; ii) align incentives to promote biodiversity conservation and sustainable use; and iii) internalize costs and benefits in the given ecosystem.
Step D. Adaptive management over space		
	Principle 3 Principle 7	Ecosystem managers should consider the effects of their activities on adjacent and other ecosystems. The EA should be undertaken at the appropriate spatial scale
Step E. Adaptive management over time		
	Principle 7 Principle 8 Principle 9	The EA should be undertaken at the appropriate temporal scale. Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term. Management must recognize that change is inevitable.

From: Shepherd, G. (ed.). 2008. *The Ecosystem Approach: Learning from Experience.* Gland, Switzerland: IUCN: p. 5.

Case Studies

Introduction of Nile Perch in Lake Victoria
One example involving invasive alien species and the disturbance of an ecosystem was the infamous introduction of the Nile Perch in Lake Victoria in Africa, which has led to the extinction or near-extinction of hundreds of native fish species (Balirwa et al., 2003; Ogutu-Ohwayo, 1990; Witte et al., 2000). Lake Victoria was historically host to more than 500 to 600 species of cichlid fish species (Balirwa et al., 2003; Witte et al., 2000). Commercial fishing started at the beginning of the 1900s in Lake Victoria, and this put pressure on several native species of fish (Ogutu-Ohwayo, 1990), reducing the **resilience** of the system. In the 1950s and 1960s several species of fish were introduced in the lake, mainly to enhance the commercial fisheries which were increasingly relying on exporting their products. One of these species, the Nile Perch (*Lates niloticus*) is a large predatory fish that feeds on fish of a wide range of sizes. Predation by the Nile Perch in combination with increased competition between other introduced species and native species, as well as fishing pressures have pushed over 200 native species over a population **threshold** and led them to extinction or near-extinction (Ogutu-Ohwayo, 1990; Witte et al., 2000).

A **regime shift** (a rapid reorganization of an ecosystem from one relatively stable state to another) took place as the fish communities previously dominated by cichlids became dominated by the voracious Nile Perch. An ecosystem approach would have prevented this disaster. The Nile Perch is now heavily fished, largely for an export market, reducing its population levels (Witte et al., 2000); this has allowed a resurgence of some native species. However, the original ecosystem has not been restored—the communities are still different than prior to the introduction since many species have disappeared and conditions in the lake have also changed because of adjacent land-use changes around the lake (Witte et al., 2000; Balirwa et al., 2003). This demonstrates the **path-dependency** of a major regime shift in an ecosystem. We return to this case study in Module 12 as we discuss the link between conflict and ecosystem (mis)management.

Sea Urchin populations in the Caribbean
Another example is the massive decline in the sea urchin population caused by a pathogen in the Caribbean, coupled with increased nutrient input from agriculture, which has led to a regime shift towards coral reefs being overgrown with brown algae (deYoung et al., 2008; Knowlton, 2001). The regime shift was preceded by a pre-conditioning stage: land-use changes increased nutrient loading and overfishing reduced populations of herbivorous fish species. These two combined factors negatively affected the **resilience** of the system, making it more vulnerable to external perturbations, though sea urchins remained as the main grazers keeping brown fleshy algae under control.

The **regime shift** was triggered by a species-specific pathogen that led to a crash in sea urchin (*Diadema antillarum*) densities to 1% of their original level. The pathogen hit in 1983, and "[b]y February 1984, *D. antillarum* had been virtually eliminated from all of its range, with the exception of populations in the eastern Atlantic, making this the most extensive and severe mass mortality ever reported for a marine organism" (Knowlton, 2001: 4822; a massive sea star collapse of the west coast of the United States in 2014-15 may have superseded this, however). Sea urchin populations were decimated within days of being affected by the pathogen, and population size reached a **threshold** (a point or level at which new properties emerge in a system, invalidating predictions based on mathematical relationships that applied until then) under which population growth was negative (Knowlton). This pushed the system over the threshold, and reefs rapidly became overgrown with brown fleshy algae, shifting to a **new persistent regime (regime shift)**. Though the time scale of the regime shift was relatively short (1-2 years), the new regime has persisted in some areas over 20 years. An ecosystem approach to Caribbean fisheries management may have prevented this calamity, since the ecosystem resilience would have been stronger if fish stocks had not been decimated prior to the pathogen's sudden appearance.

Discussion Points

1. Name some feedback mechanisms, regimes shifts, and other mechanisms that characterize complex adaptive systems, using ecosystems you are familiar with or live nearby.
2. What ecosystem services affect your daily life? Could you live without them?
3. In the context of ecosystem services: what are some of the advantages and disadvantages of putting financial values on natural processes?
4. In what ways is the ecosystem approach to environmental management different from conventional approaches based on an equilibrium view of ecosystems?
5. What are some of the challenges of using the ecosystem approach in the management of ecosystems that you are familiar with or live nearby? You can discuss this question from your own professional point of view, whether you are a manager of resources, an environmentalist, or some other form stakeholder.

Annotated bibliography:

Alcamo [et al.]. 2003. "Chapter 2: Ecosystems and Their Services." In *Ecosystems and Human Well-Being: A Framework for Assessment*, 71–84. Millennium Ecosystem Assessment. Available online: http://www.millenniumassessment.org/en/Framework.html. *This chapter from the first report submitted by the Millennium Ecosystem Assessment presents the ecosystem services framework developed as part of this major global endeavour. It includes a description of ecosystems, of the ecosystem approach as well as the various types of ecosystem services that form this framework.*

Costanza, Robert, Rudolf de Groot, Paul Sutton, Sander van der Ploeg, Sharolyn J. Anderson, Ida Kubiszewski, Stephen Farber, and R. Kerry Turner. 2014. "Changes in the Global Value of Ecosystem Services." *Global Environmental Change* 26 (May): 152–58. doi:10.1016/j.gloenvcha.2014.04.002. *This paper provides a current portrait of the global value of ecosystem services, comparing recent (2011) values with ones from previous studies (1997). It also examines the impacts of land-use changes that have taken place during this period on the global value of ecosystem services.*

Gibson, J., L. Wilson, J. Kelly, O. Vestergaard, N. Bowles-Newark, M. Strubel, A. Crowther, M. Fancourt, and C. Brown. 2014. "Towards an Integrated Approach to Managing Ecosystems." Cambridge: United Nations Environment Programme World Conservation Monitoring Centre. *This UNEP publication presents a synthesis of literature on ecosystem approaches to environmental management. It takes a very practical approach, and includes a series of case-studies from all over the world.*

Holling, C. S. 2001. "Understanding the Complexity of Economic, Ecological, and Social Systems." *Ecosystems* 4 (5): 390–405. doi:10.1007/s10021-001-0101-5. *This paper presents an overview of the adaptive cycle and panarchy, as theoretical frameworks to understand complex adaptive systems. Providing examples from social and ecological systems, it reviews the key features of the adaptive cycle and of panarchy.*

Lele, Sharachchandra, Oliver Springate-Baginski, Roan Lakerveld, Debal Deb, and Prasad Dash. 2013. "Ecosystem Services: Origins, Contributions, Pitfalls, and Alternatives." *Conservation and Society* 11 (4): 343. doi:10.4103/0972-4923.125752. *This paper presents a review of the literature on Ecosystem services as an analytical concept for nature-society relations. It discusses the reasons for its attractiveness, the contributions it has made to research and practice, as well as highlights some inconsistencies that underlie the concept.*

Shepherd, G. (ed.). 2008. *The Ecosystem Approach: Learning from Experience.* Gland, Switzerland: IUCN. X + 190pp. Available online: https://portals.iucn.org/library/efiles/edocs/CEM-005.pdf *This edited volume presents a series of case-studies where the IUCN is involved with the stated intention to apply the ecosystem approach. These case studies, from all over the world, include forestry, fisheries, agriculture and livestock herding, often in conjunction with protected areas. They also cover a range of different biomes and ecosystems.*

Recommended websites

The "Ecosystem" page on the *Encyclopedia of the Earth* provides a wealth of information on ecosystems including the history of the concept, the structures and functions of ecosystems, research done on ecosystems as well as links to other resources: http://www.eoearth.org/view/article/152248/

The Resilience Alliance is a research partnership working on issues related to resilience. Their website contains valuable information regarding ecosystem dynamics including panarchy and the adaptive cycle, as well as lists of publications about resilience: http://www.resalliance.org/panarchy

The Convention on Biological Diversity has a lot of material on the ecosystem approach, including definitions, guiding principles, cases studies, and a newsletter. All this material can be accessed from the following website: https://www.cbd.int/ecosystem/default.shtml

The International Union for the Conservation of Nature (IUCN) Commission on Ecosystem Management's website contains, again much information on this approach, including all the work done by the various working groups of the Commission, including numerous reports that include case-studies: https://www.iucn.org/about/union/commissions/cem/

Project PISCES (Partnerships Involving Stakeholders in the Celtic Sea Ecosystem) is a marine management project linking people from the major sectors operating in the Celtic Sea. It is a project applying ecosystem management, and this website contains both theoretical information about the ecosystem approach as well as practical information from this case-study: http://www.projectpisces.eu/about_us/

Under the auspices of the UN, the Millennium Ecosystem Assessment sought to "the objective of the MA was to assess the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being." It took place from 2001 to 2005, and its history, findings and reports can be accessed at: http://www.millenniumassessment.org/en/index.html

Launched after the Millennium Ecosystem Assessment, the Economics of Ecosystems and Biodiversity (TEEB) is a global initiative that seeks to "make nature's values visible". Its main objective is to mainstream the values of biodiversity and ecosystem services into decision-making at all levels, and their work involves attributing value to these assets. Their website contains many reports as well as numerous case studies.
http://www.teebweb.org/resources/ecosystem-services/

Module 3: Human Dimensions

Expected Learning Outcomes: upon completion of this module, students will be able to

- explain the concept of social-ecological systems as complex adaptive systems
- understand why we need to integrate the human dimension in environmental management and governance
- explain and apply the social wellbeing framework to analyze social-ecological systems
- differentiate management from governance and contrast the main environmental governance and management systems (community-based, collaborative, top-down)
- define adaptive management and governance and list their requirements
- explain why management and governance need to be adaptive and how they can respond to the requirements of systems thinking
- understand the basic requirements of effective public participation and why it is needed

The Importance of the Human Dimension of the Ecosystem Approach

We envisage a world in which every country enjoys sustained, inclusive and sustainable economic growth and decent work for all. A world in which consumption and production patterns and use of all natural resources – from air to land, from rivers, lakes and aquifers to oceans and seas - are sustainable. One in which democracy, good governance and the rule of law as well as an enabling environment at national and international levels, are essential for sustainable development, including sustained and inclusive economic growth, social development, environmental protection and the eradication of poverty and hunger. One in which development and the application of technology are climate-sensitive, respect biodiversity and are resilient. ***One in which humanity lives in harmony with nature and in which wildlife and other living species are protected****.*
Paragraph Nine, Transforming Our World: The 2030 Agenda for Sustainable Development
https://sustainabledevelopment.un.org/post2015/transformingourworld

We have entered the era of the Anthropocene: the human impact on the natural environment is so fundamental today that many scientists are referring to ours as a new geological era. As such, an ecosystem approach is more vital than ever. Importantly, and contrary to what many people may think, an ecosystem approach does not rely solely on the natural sciences (biochemistry, taxonomy, botany, etc.). In fact, in a world where there are few pristine natural settings left and human encroachment and development is only expanding, it is more vital than ever that we integrate the human dimensions into any ecosystem approach. Decisions about ecosystem management need to address moral or ethical questions, but ecological principles usually cannot provide answers to value-based questions. The ecosystem approach in itself tells us nothing about a system's "desirable state" -- setting goals for ecosystem management and governance will be based on human values and concerns, as well as the interplay of various political agents in various positions of power.

The concept of **socio-ecological systems** is helpful here. Humans are unique mammals (due to human cognition) and we interact with ecological systems in a unique way (Westley et al., 2002). Since different groups of people will value different aspects of their environment, which in turn will influence their culture and way of life, the ecosystem approach needs to be sensitive to both the ecological and social contexts. Social systems are even more complex than ecosystems, since complexity arises from the many interactions between individuals, which may cause changes in the group as a whole (e.g. norms), which in turn affect the conditions for individual behavior. Social and ecological systems "are intimately linked: humanity depends on services of ecosystems for its wealth and security. Moreover, humans can transform ecosystems into more or less desirable conditions. Humanity receives many ecosystem services, such as clean water and air, food production, fuel, and others. Yet human action can render ecosystems unable to provide these services, with consequences for human livelihoods, vulnerability, and security" (Folke et al., 2002, p. 437).

The social-ecological system (SES) concept arose when "[i]ntegrated studies of coupled human and natural systems revealed new and complex patterns and processes not evident when studied by social or natural scientists separately" (Liu et al., 2007:1513). It refers to an "ecological system intricately linked with and affected by one or more social systems. […] Both social and ecological systems contain units that interact interdependently and each may contain interactive subsystems as well" (Anderies et al., 2004). There are different terms used in the literature to capture this idea, such as: coupled human and natural system (CHANS), human ecosystems, ecosocial systems, coupled human-environment systems, and socioecological systems.

This perspective also builds on the Millennium Ecosystem Assessment we introduced in Module 2. The MEA focused on drivers of change, human well-being and ecological services, and recognized that SES are uncertain and complex; feedbacks are manifested in ways that are not necessarily predictable. The SES concept makes explicit the two-way linkages between social and ecological systems. This includes links related to policies, management institutions, people's knowledge (e.g., local or traditional knowledge), as well as informal social rules and norms that influence how humans interact with the environment. It also emphasizes that the couplings between social and ecological systems constitute *a new complex adaptive system with its own emergent properties and feedbacks* (Berkes et al., 2003; Gunderson & Holling, 2002; Waltner-Toews & Kay, 2005). "Couplings between human and natural systems vary across space, time, and organizational units. They also exhibit nonlinear dynamics with thresholds, reciprocal feedback loops, time lags, resilience, heterogeneity, and surprises. Furthermore, past couplings have legacy effects on present conditions and future possibilities" (Liu et al., 2007, p. 1513), reflecting the theme of **path-dependency** introduced in our first module.

Another related concept we've already discussed in this course is **resilience**, which can be applied to social systems when examining the ability of human communities to "withstand external shocks to their social infrastructure, such as environmental variability or social, economic and political upheaval. Systems may be ecologically resilient but socially undesirable, or they may be socially resilient but degrade their environment" (Berkes & Folke, 1998:354). **Social-ecological resilience**, on the other hand, is related to

(i) the magnitude of shock that the system can absorb and remain within a given state;
(ii) the degree to which the system is capable of self-organization; and
(iii) the degree to which the system can build capacity for learning and adaptation. "When massive transformation is inevitable, resilient systems contain the components needed for renewal and reorganization. In other words, they can cope, adapt, or reorganize

without sacrificing the provision of ecosystem services. Resilience is often associated with diversity – of species, of human opportunity, and of economic options – that maintains and encourages both adaptation and learning" (Folke et al., 2002:438).

Human Well-being

In the last decade, the concept of human well-being has attracted increasing attention in both research and policy. Countries such as Canada, the UK and France are taking steps to include well-being in policy processes and China has formally integrated well-being goals in its national objectives. In Latin America, indigenous conceptions of well-being are at the forefront of policy discourse and are popularly referred to by the umbrella term *Buen Vivir* ("living well"). Well-being is often framed as a desired target or an outcome; this is how it is used in the MEA, one of the first efforts to substantially incorporate considerations of human well-being into how ecosystem dynamics are comprehended. And as the quotation from the 2030 Agenda for Sustainable Development offered at the front of this chapter indicates, living in harmony with nature is now conceived as essential to human well-being.

However, our understanding of well-being has deepened since 2005. For example, the UN Permanent Forum on Indigenous Issues has put together a list of 12 core themes and issues reflecting indigenous notions of well-being that were not appropriately captured in previous definitions (Dandeneau et al., 2008):

1. Security of rights to territories, lands and natural resources
2. Integrity of indigenous cultural heritage
3. Respect for identity and non-discrimination
4. Culturally-appropriate education
5. Fate control/self-determination
6. Full, informed and effective participation
7. Health
8. Access to infrastructure and basic services
9. Extent of external threats
10. Material well-being
11. Gender
12. Demographic patterns of indigenous peoples

The "social conception of well-being" developed by the Research Group on Well-being in Developing Countries (WeD) (Gough and McGregor 2007) is a simple framework, yet it is able to capture dimensions that are of relevance for indigenous peoples and multiple cultures. Importantly, the concept can be used to help unpack some of the main elements that drive people's choices and behaviour. It is also promising for its ability to dynamically link human interests and ecological systems (Armitage et al., 2012). It stresses three dimensions:

a) The **Material dimension** "encompasses practical welfare and physical requirements of life, such as income, wealth, assets, physical health, the ecosystem services provided by the physical environment and livelihood concerns among others" (Armitage et al., 2012:4).

b) The **Relational dimension** "emphasizes social interactions, networks of support and obligation, collective actions, and the relationships involved in the generation and maintenance of social, political, and cultural identities. These include relations to the state and to formal and informal societal structures which determine the scope for personal action and influence in the community" (Armitage et al., 2012:4). This dimension is especially important for close-knit communities and indigenous peoples.

c) The **Subjective dimension** "incorporates cultural values, norms, and belief systems, and importantly, accounts for notions of self; individual and shared hopes, fears, and aspirations; expressed levels of satisfaction or dissatisfaction; trust; and confidence" (Armitage et al., 2012:4). Importantly, it accounts for the agency people exert in negotiating their adaptation strategies, and how this feeds back into the resilience of the social-ecological system (Coulthard, 2012).

The subjective and relational dimensions of well-being allow us to consider issues related to people's preferences and identity which are not necessarily aligned with social-ecological resilience (Coulthard, 2012). For example, it is well documented that many fishers will resist leaving the fishing occupation even when reduced economic returns suggest they should. Fishers frequently describe fishing as being more than a livelihood, but an entire way of life, to which they are strongly attached (Pollnac & Poggie, 2008). Even if leaving the fishery in search of another job could improve the resilience of their household through increased and more stable revenue and improve the resilience of the ecosystem through reduced fishing pressure, it does not necessarily mean that it would increase their well-being. This is an often-overlooked aspect of solving the wicked problems we confront today. Combining the social well-being and the social-ecological resilience frameworks can assist in assessing and comparing trade-offs that include: "(1) those that involve critical ecosystem services and their feedbacks across scales, and (2) those that involve the material, relational, and subjective dimensions of the social world linked with an ecological context" (Armitage et al., 2012, p. 6).

Adaptive Governance and Public Participation

The terms "management" and "governance" are often used interchangeably but we employ different meanings in this course. **Management refers to the technocratic implementation of policies, while governance is a much broader term related to the power configurations that result in those policies in the first place.** Governance is "about sharing responsibility and power; it is about setting the policy agenda and objectives and about the processes of implementing management actions" (Béné & Neiland, 2006:10–11); it "consists largely of negotiating conflict, making compromises and building (temporary) consensus, and leadership is not so much about the exercise of authority as about political brokerage, where conflicts are not necessarily resolved" (Jentoft, 2007, p. 362). The UNDP (2007) defines governance as "the system of values, policies and institutions by which a society manages its economic, political and social affairs through interactions within and among the state, civil society and private sector." Interactive governance theory recognizes three ideal types of governing modes: hierarchical governance, co-governance, and self-governance (Kooiman et al., 2005) which correspond at the management level respectively to: top-down management, co-management and community-based management. In reality, a range of different collaborative governance arrangements usually co-exist within social-ecological systems.

Dealing with wicked problems and SES dynamics requires (Folke et al., 2005) learning to live with change and uncertainty, combining different types of knowledge for learning, creating opportunities for self-organization toward social-ecological resilience, and nurturing sources of resilience for renewal and reorganization. Key features of adaptive governance include (Munaretto et al., 2014):

- Networks, and polycentric institutions (shared power)
- Collaboration and public participation
- Integration of different types of knowledge
- Flexibility to adapt to change, focus on developing adaptive capacity
- Enabling resilience management
- Building learning strategies, experimentation (learning-by-doing)
- Creating social and institutional memory
- Matching scales of governance to the scale of ecosystems

A key component of adaptive governance is public participation, which may very well be time-consuming and complex, but wields many benefits in the pursuit of solutions to wicked problems, such as the ability to build local skills, interests and capacities; the ability to improve outcomes by extending the range of values and inputs into the decision-making process; and the increased probability of acceptance and successful implementation when decisions are seen by those involved as responsible and appropriate (this is also known as **legitimacy**). Wide consultation with all relevant stakeholders is a challenging concept, but it is essential that people agree on the nature of the problem before seeking solutions that will require their long-term commitment. Dialogue is the only effective way to overcome stark and subtle differences in cultural perspectives. Often, social and cultural norms can obscure the perspectives and knowledge of certain members of a community (e.g. women, marginalized groups).

There is a wide range of participatory methods that can be used to engage in consultation with different stakeholders, from simple group meetings to more technical methods such as participatory mapping or modeling, to more creative methods such as participatory photography/video or even theater. Scenario-based methods are often presented as useful tools for building social-ecological resilience (e.g. Folke et al., 2002) or sustainability (e.g. MEA, 2005). A field guide was developed collaboratively by the Center for International Forestry Research (CIFOR), the ASB-Partnership for the Tropical Forest Margins, a system-wide program of the Consultative Group on International Agricultural Research (CGIAR), the World Agroforestry Centre (ICRAF) and the Secretariat of the MEA (Evans et al., 2006). This guide presents four participatory methods to assist communities to think about the future:

a) **Scenarios** is a method for developing plausible stories about the future, each of which might happen under particular assumptions. A group of assembled people try to answer the question: “What if…?”. Writing scenarios encourages participants to consider the range of changes or surprises that are likely to occur in the future and to think about their impacts. The goal of this method is to consider a variety of possible futures rather than to focus on the accurate prediction of a single outcome.

b) **Projections** is a method to forecast of the future based on current trends. "Projections are usually more analytical than creative, calculating a single expected outcome of a current trend or a range of statistical possibilities. Projections work best for short-term forecasting, since, unlike Scenarios, they do not take into consideration uncertainties or unforeseen events. This method is also known as trend analysis and is used by economists and planners" (Evans et al., 2006, pp. 6–7).
c) **Visioning** is a way for people to consider a single future—their ideal future—in depth. The purpose is to provide a way for people to articulate their hopes, share them and arrive at a consensus about a common vision for their community" (Evans et al., 2006, p. 7).
d) **Pathways** is a method for reaching a goal in the future by devising specific strategies and action plans. Pathways frequently are follow-up exercises to other methods for thinking about the future, such as Visioning or Scenarios (Evans et al., 2006, p. 7).

These are just some of the methods that can be used to ensure greater public participation in decision-making. The need for this interaction cannot be overstated. Nor can the need, stressed by UNEP in recent decades, for cross-sectoral collaboration. For example, UNEP has recently declared, "the solution to delivering the SDGs lies in pursuing an integrated approach that incorporates economic, social and environmental dimensions into the heart of economic decision-making, particularly in national planning and budgeting processes." Indeed, the human dimension will always be an integral aspect of the ecosystem approach, and adaptive governance will need to reflect this reality.

Transboundary Challenges[1]

The challenges of preventing and resolving conflicts over renewable natural resources often extend beyond national borders. This is particularly the case for water, wildlife, fisheries and air quality. Similarly, risks to renewable resources from waste management, pollution, climate change and disasters are often transboundary in nature. While states have - in accordance with the UN Charter and the principles of international law - the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, they also have the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other states. Furthermore, Principle 2 of the Rio Declaration refers to the issues of sharing in the use and management of resources that move across international borders. Yet, transboundary dynamics are often beyond the capacity of a single sovereign state to manage unilaterally, requiring cooperation and co-management with neighboring countries.

[1] This section was written by UNEP: http://www.un.org/en/land-natural-resources-conflict/pdfs/GN_Renew.pdf

There are four main types of transboundary dynamics and pressures that can cause conflicts over renewable natural resources. First, when transboundary natural resources such as water or fisheries are shared between countries, conflicts can arise when one country consumes the resource at higher rates than another, violates agreed allocations or demonstrates inflexibility when faced with natural variation. This is often linked to existing power and political economy dynamics, as well as with the bargaining power associated with their geographic location (upstream/downstream). Alternatively, a lack of sound data on resource consumption rates, quantity and quality can cause inaccurate perceptions leading to unfounded accusations.

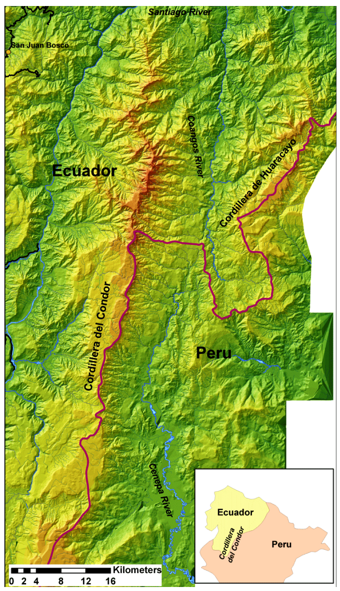
Second, when the quality or quantity of transboundary natural resources, such as water, fisheries, wildlife and air, is negatively impacted in one country by infrastructure, industrial development or changes in land use in another country. In particular, pollution generated in one country can easily cross national borders, creating health risks in another. Similarly, changes in land use in one country, including high levels of deforestation and soil erosion, can heighten vulnerabilities to natural hazards in another.

Third, while national borders define the sovereign boundary of states, these are often not respected by pastoral livelihood groups that migrate on a seasonal basis along traditional routes, based on the availability of natural resources such as water and grazing land. Similarly, wildlife populations commonly migrate across national boundaries, shifting economic opportunities from one country to another. Both situations can be important sources of conflict as user groups are faced with increasing competition or lost livelihoods. In addition, this may result in the loss of indigenous communities and their cultural and spiritual heritage.

Finally, one of the emerging threats to the natural resource base of countries comes from illicit activities and criminal groups operating on a global and transboundary basis. Illicit extraction and trade of natural resources deprives local communities of resource benefits and can lead to conflict. At the same time, pressures such as violent conflict, disasters or environmental degradation can be powerful incentives for people to migrate across borders, establishing new resource-dependent livelihoods in neighboring countries that fall outside of government regulation and control.

While the international community has adopted various conventions, declarations and legal statements concerning the management of transboundary natural resources, significant institutional gaps remain. In particular, effective joint management and monitoring structures, coordinated laws and policies, and mechanisms for enforcement and dispute resolution are lacking. Efforts to integrate an ecosystem approach into conflict resolution are particularly wicked problems fraught with uncertainty and dangers. Yet as the following case study demonstrates they can also meet with some success.

Case Study
Resolving Border Conflicts Through Peace Parks



Ecuador/Peru border dispute: For the greater part of the 20th century, Ecuador and Peru have had incompatible claims over the territory known as the Cordillera del Condor. The Condor mountain range is one of the most important ecosystems in the world (Conservation International), and is home to an important number of indigenous populations. Military conflict materialized in 1995 and a peace treaty was signed and further implemented in 1999. Part of the resolution scheme hinged upon creating a protected area along the Condor periphery, which would be jointly administered by both countries. This area is now called the Condor-Kutuku Peace Park, and is a prime example of how a conservation-based strategy was used for peacebuilding in a conflict zone.

From a traditional conflict perspective, this case is an excellent example of an interstate dispute over territory that was resolved by way of environmental variables, specifically environmental conservation. After war was initiated by Ecuador and Peru in 1995, a peace agreement was brokered by Argentina, Brazil, Chile and the US, which subsequently led to a fully implemented "Brasilia Presidential Act" in 1999. A major component of this agreement included the need to establish adjacent zones of ecological protection on both sides of the border. This clause led to the creation of the Condor Park in Ecuador and the Zone of Ecological Protection in Peru, comprised of 25.4 and 54.4 square kilometers respectively. In addition to this, subsequent agreements for binational environmental cooperation and protection have been instituted, whereby decision-making processes are dictated by steering committees comprised of policy-makers from both countries. However, these projects still require the steadfast inclusion of the human dimensions, including the participation of local affected communities, if they are to be successful in the long term.

Discussion points

1. How should we address trade-offs between human wellbeing and resilience?
2. In what type of situations are hierarchical, collaborative or community-based governance more appropriate? What are the advantages and disadvantages of each?
3. Who should be involved in identifying relevant stakeholders? How can this be made a transparent and equitable process?

4. Have you ever been involved in decision-making about an issue that will affect an ecosystem? Can you identify some of the key concepts discussed in this MOOC in the process?
5. Can the ecosystem approach be applied across borders – or is simply too complicated to apply the human dimensions to this task?

Annotated Bibliography

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Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). "Adaptive Governance of Social-Ecological Systems." *Annual Review of Environment and Resources*, *30*(1), 441–473. *This article reviews experiences of adaptive governance of social-ecological systems using the framework of the adaptive cycle. It illustrates how resilient social-ecological system may make use of crisis as an opportunity to transform into a more desired state.*

Kooiman, J. (2003). "Part II: Modes of Governance. *Governing as governance"* (pp. 77–132). London: SAGE Publications Inc. *This book section contains three chapters each exploring in detail one of the three modes of social governance.*

Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., et al. (2007) "Complexity of Coupled Human and Natural Systems." *Science*, *317*(5844), 1513–1516. *This article provides a synthesis of 6 case studies adopting a social-ecological framework (referred to as coupled human and natural systems (CHANS) in the article). It demonstrates the following: (1) couplings between human and natural systems vary across space, time, and organizational units; (2) they exhibit nonlinear dynamics with thresholds, reciprocal feedback loops, time lags, resilience, heterogeneity, and surprises; and (3) past couplings have legacy effects on present conditions and future possibilities.*

Stepp, J. R., Jones, E. C., Pavao-Zuckerman, M., Casagrande, D., & Zarger, R. K. (2003). "Remarkable Properties of Human Ecosystems." *Conservation Ecology*, *7*(3), article 11. *This article explores some of the properties that differentiate social-ecological systems (referred to as human ecosystems in the paper) from nonhuman ecosystems. It presents a framework that*

bridges biological ecology and human ecology centered on human cognition and behavioral abilities.

Recommended websites

Smithsonian video: What is the Anthropocene and are we in it?
http://www.smithsonianmag.com/science-nature/what-is-the-anthropocene-and-are-we-in-it-164801414/?no-ist#ooid=JzajdmeTp-rZW6QciB-u9Gbidlecsb8f

Article published in The Guardian on January 7, 2016 on the Anthropocene.
http://www.theguardian.com/environment/2016/jan/07/human-impact-has-pushed-earth-into-the-anthropocene-scientists-say

Short Film that opened the Rio +20 summit: Welcome to the Anthropocene
http://anthropocene.info/short-films.php

Ideas @Davos. Ocean Mercier argues the value of using indigenous knowledge alongside Western science to achieve sustainability, using Maori navigation knowledge as an example.
https://www.youtube.com/watch?v=SoQS_7yjStE

Seven principles for building resilience in social-ecological systems. White board animation http://www.stockholmresilience.org/21/research/research-news/2015-02-19-applying-resilience-thinking.html

Social-ecological innovations. Following the publication of a chapter in a new book titled "Social Innovation — Blurring Boundaries to Reconfigure Markets", Dr. Per Olsson from the Stockholm Resilience Centre discusses the concept of "social-ecological innovation"
http://www.stockholmresilience.org/21/research/research-videos/2012-04-20-social-ecological-innovations.html

Nobel Laureate Elinor Ostrom explains the concept thinking behind the tragedy of commons and how to go beyond it.
https://vimeo.com/19976198

Global Environmental Governance: Fixing a troubled system. IISD Senior Fellow Adil Najam talks about the need for urgent reform of our system of global environmental governance needs—not because it has failed, but because it has outgrown its original design
https://www.youtube.com/watch?v=vDvqJ9yJnLQ

Global Environmental Governance: Quest for Symphony. This 15 minute documentary outlines the past, present, and future of global environmental governance centered on interviews with key participants at the 25th United Nations Environment Programme's Governing Council/Global Ministerial Environment Forum in Nairobi, Kenya in February 2009.

https://vimeo.com/5390040

Environment and peacebuilding in wartorn societies: Lessons from the UN Environment Programme's experience with post-conflict assessment (Ken Conca and Jennifer Wallace):
http://www.environmentalpeacebuilding.org/assets/Documents/LibraryItem_000_Doc_062.pdf

Short talk by Brian Walker:
http://www.stockholmresilience.org/21/news--events/seminar-and-events/whiteboard-seminars/2-2-2013-managing-feedbacks-in-social-ecological-systems.html

Module 4: Biodiversity

Expected Learning Outcomes: upon completion of this module, students will be able to

- define biodiversity as it is defined by the United Nations
- identify some of the ecosystem services and functions and contributions to human well-being provided by biodiversity
- define a keystone species and predict the potential results of removing this species
- identify a regime shift caused by loss of biodiversity
- understand the concepts of functional redundancy and response diversity and their importance in terms of resilience
- understand and be able to reflect upon how humans affect and are affected by biodiversity, including discussion of the main threats to biodiversity and the strengths and weaknesses of various types of conservation actions.

Biodiversity as a Social-Ecological System

It is time to learn from nature. We might view biodiversity as the ongoing product of billions of years of natural evolution on the planet Earth, and we can use the lessons learned from this to understand how we can better mimic resilient natural solutions to the problems we face today (see https://biomimicry.org). This module presents an overview of some of the basic ideas behind biodiversity science today, but students should bear in mind their utility in solving problems from an ecosystem approach.

There are many definitions of biodiversity available, including rather generic versions, such as that "[biodiversity is] the variety of life and its processes" (U.S. Forest Service 1990). More precisely, it is often discussed in terms of diversity at three levels: the genetic level, the species level, and the ecosystem level. This is reflected in the 1992 United Nations Convention on Biological Diversity (CBD) definition of biodiversity: "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 within species, between species, and of ecosystems" (Article 2).

Genetic diversity refers to the variety of different genotypes or alleles; when it is not present, species will inbreed, causing severe problems. Species diversity refers to the variety of different species; this is the most common association people make with the term "biosecurity." And ecosystem diversity refers to the variety of different ecosystems within a bioregion or, even, at the global level. In reality, these three components are intertwined and involve several other layers of diversity, including the cultural diversity inherent in human communities. To account for this, in a paper published in 1990, Reed Noss conceptualized biodiversity in a multi-faceted, hierarchical way, as being composed of compositional, structural, and functional elements. Composition refers to which species, genotypes, ecosystems or landscapes exist in a given area. Structure corresponds to spatial and temporal organization (such as whether landscapes are fragmented or not). Function refers to the roles carried out by the different components, from control of landscape-scale processes such as floods (through, for example, the absorption of storm water by roots), to genetic processes including natural selection.

As mentioned in Module 2, biodiversity (and its interaction with non-living resources) provides a multitude of **ecosystem services:**

- Provisioning: food, construction material, medicinal resources, artistic material, etc.
- Regulating: Climate regulation, water purification, waste treatment, infectious disease regulation, pest control, etc.
- Cultural: Recreation, tourism, cultural identity, spiritual functions, science and education, etc.
- Supporting: nutrient cycling, primary production, etc.

One popular example of ecosystem services provided by biodiversity is **pollination**. A large proportion of the agricultural crops we consume are pollinated by insects (often bees), birds, or bats. Colony collapse disorder (resulting in reductions in some bee populations due perhaps to disease or pesticide use) has cast public attention on the key role that bees play in our economies. However, even in the absence of disease or pesticides, bees would not survive were it not for other components of biodiversity. Trees filter air and water, store carbon, and regulate temperature; if there were no trees on the earth, perhaps bees would not be able to survive the resulting levels of air pollution. Bees are protected from predation because of their bright warning coloration. If there were not an abundance of other similarly-colored toxic or stinging insects around to reinforce the warning message of this coloration, bees might be subject to much greater predation pressure. Since most plants flower only for part of the summer, a diversity of flowering plants is crucial to the survival of bees, who must eat throughout the summer. One study has even found that the presence of natural habitat in agricultural areas and in particular the diversity of other insects and birds that come with this natural habitat increases the pollination effectiveness of bees by making them move more from one plant to another as they avoid potential predators and competitors (Carvalheiro et al. 2011). Thus, biodiversity in general contributes to the pollination service provided directly by bees, which in turn provides us with food security. Unfortunately, pollinators are under enormous pressures today and several species are even threatened with extinction. A 2016 assessment by the Intergovernmental Platform on Biodiversity and Ecosystem Services stressed the key relationship between pollinators and 75% of the world's food crops at an annual value in the region of US$235-$577 billion.

Returning to Module 3, biodiversity is also linked with three prominent dimensions of human well-being:

- **Material dimension**: people across the world are fed by biodiversity and use the material components of biodiversity in a multitude of ways to meet their daily needs in terms of income (such as wood for construction), food (pollination services, hunting, trapping), physical health (pharmaceutical products), etc. The CBD now has a cross-cutting programme on biodiversity and health in which well-being is recognized as a critical component.
- **Relational dimension**: biodiversity provides opportunities for social interaction (such as the social and cultural importance of baobab trees) and the relationships involved in the generation and maintenance of cultural identities (such as the importance of woodland caribou to Cree communities in northern Quebec).
- **Subjective dimension**: biodiversity is often linked to cultural identity. For example, some Maori communities of New Zealand define themselves in terms of the inshore aquatic species that are the most common or most valued in their area. These species are termed 'cultural keystone species' (McCarthy et a. 2014).

The interactions between species (food webs, competitive interactions, etc.) form complex adaptive systems, as do the ecosystem services and functions provided by the various living components of the system. This leads to competing and complimentary uses and interactions among stakeholders, as seen in community-based forest management in Honduras, where trees are used for logging, resin-tapping, firewood, charcoal, handicrafts, and other purposes (Nygren 2005).

Indeed, different components of biodiversity may be important in different ways for different reasons. For example, lions are important to African park managers because tourists pay money to see them; they bring revenue and jobs, adding to the local economy. They are also important spiritually and culturally, as symbols of strength and beauty. They also play important roles in the ecosystem, as top predators capable of controlling populations of ungulates, picking off the weak, and thus regulating the consumption of local flora. Thus, lions may be important to us, but also to ecosystems, and thus to other components of biodiversity. If ungulate populations were not controlled, the biomass that they eat would be drastically reduced, harming other organisms (insects, birds, etc.) that depend on them. It is possible that without lions, ecosystems would collapse, flipping into an alternate stable state qualitatively different from the current grasslands where they live. As discussed in previous modules, the results of these regime shifts may have far-reaching implications and are hard to predict until they actually occur. Various components of biodiversity may provide us with crucial ecosystem services, but they also contribute to the maintenance of biodiversity in general and therefore to system stability and resilience.

This does not necessarily mean that all species are crucial to the functioning of ecosystems and the provision of ecosystem services. Ecosystems are such complex webs of interaction that it is often impossible to predict which components are crucial in which ways without going through the dangerous and often irreversible experiment of removing ecosystem components one at a time. And it is always vital to remember that what happens in one ecosystem can affect another.

A **keystone species** is one for which the removal from the system will lead to a **regime shift**. In 1969, Robert Paine described a food web that collapses when the top predator, the sea star, is removed. (Sadly, we may be seeing this occur off the west coast of the United States today, where a massive sea star die-off has been attributed to a combination of disease and temperature fluctuations.) There is also a great deal of research currently being carried out to identify functional traits that would help us to figure out which species might be more important to conserve than others in terms of functional redundancy and response diversity, particularly in plant communities (Elmqvist et al. 2003).

So far, we have had more success in identifying tipping points after than before the fact, but we do know that, in general, the more biodiversity there is, the less likely the system is to reach a tipping point.

A biological community is likely to be resilient if it has both high functional redundancy and high response diversity. Here, function refers to the role each species plays in the system. For example, the lion is the top predator in the African savannah. If there are many top predators, the system has **functional redundancy**: it will likely not collapse if one of these top predators is removed because the others will carry out its role in controlling ungulate populations. In other words, it will be somewhat resilient to the loss of one of these top predator. However, if there is only one main top predator, as in the example of the wolves in Yellowstone National Park (described in Module 6), its disappearance may result in ecosystem collapse, as ungulate populations soar, leading to changes in vegetation structure. (Note that, in this particular example, bears may also eat ungulates, but, being omnivores and living naturally at relatively low densities, they will not eat a sufficient number to control the population).

Response refers to the reaction of a species to disturbance, whether this is natural or anthropogenic. A system that has **response diversity** is one in which the components are not all affected in the same ways by the same disturbances. For this system to be resilient, this response diversity should be among functionally redundant species, such that, for example, only one of two top predators in a system is negatively affected by a new epidemic disease.

However, while there is no doubt that the loss of habitat is the primary cause of species declines, the effects of habitat fragmentation are unclear and may be as likely to be positive as negative when habitat fragmentation is separated from habitat loss and defined simply as the breaking apart of habitat (Fahrig 1997). Habitat loss is generally caused by development, agricultural expansion, and resource extraction. Although thus far there is only one known case of climate change leading to species extinctions (the case of the Harlequin frog and the Golden Toad in Costa Rica, Pounds et al. 2006), there is likely to be an extinction debt as feedback mechanisms associated with climate change lead to changes and loss of habitat (Thomas et al. 2004). Other direct and indirect threats to biodiversity include:

- Overharvesting: see review in Novacek and Cleland (2001) and Miller et al. (1989)
- Pollution: see review in Novacek and Cleland (2001) and Miller et al. (1989)
- Invasive species: exotic (non-native) species that cause damage to native ecosystems and native biodiversity. Invasives generally have few native predators, spread easily, and reproduce quickly, and may introduce pathogens. It is clear that invasive species cause changes in ecosystems, although less clear that they actually lead to extinctions of native species (Gurevitch and Padilla 2004 say they don't, Clavero and Garcia-Berthou 2005 say they do).
- Disease: ex: white-nose syndrome in bats (see Chapter 9 in this sourcebook; and Frick et al. 2010)
- Note that these are all wicked problems, emerging from complex interactions between social, economic, and ecological components of the system.

Biodiversity Conservation

As an international convention implemented by national parties and partners, the CBD plays a key role facilitating biodiversity conservation and the inclusion of local perspectives. In particular, Article 8(j) has been very influential in advancing the recognition of indigenous knowledge and rights with regards to environmental management and governance.

Since we are limited in our ability to identify keystone species in advance (we often notice the important role they played only once they are gone) and in our ability to predict future disturbances and the responses that the various components of the system will have, it is best to apply the **precautionary principle** and to manage with the whole system in mind, for all components of biodiversity rather than just some. This is the idea behind protected areas, and also behind the IUCN's efforts to create a red list of ecosystems in danger of collapse, thus pulling the focus away from individual species and towards whole systems. Note that the CBD Aichi target for protected areas is protected status for 17% of all terrestrial systems and inland waters and 10% of all coastal and marine systems by 2020, and despite some progress towards this target we remain quite far from its realization.

However, protected areas are not necessarily the only, nor even the best way to conserve biodiversity. They do not necessarily encompass human use, despite the fact that biodiversity has been found to be correlated globally with linguistic diversity (e.g.: the Terra-Lingua mapping project). For example, in a recent study on the importance of forest in agricultural, peri-urban and urban areas, we found that those forests that are most important for biodiversity tend to be far from residential, commercial, and agricultural areas, while those that are most important in terms of ecosystem services tend to be close to or even within these areas (Tittler *et al*. in prep). Thus, there is also an important role for natural or semi-natural habitat to be conserved close to people. The greatest challenge here may be in urban areas, where the human population is at its densest. Here backyards and green spaces may be crucial to provide people with equal, easy access to biodiversity, particularly for cultural, spiritual, and educational uses as well as for pest control. This may seem to bring up a conflict between limiting urban sprawl (and thus increasing settlement density in urban areas) and maintaining access to biodiversity for urbanites; this conflict may be addressed through rooftop, community or botanic gardens and by limiting the sizes of houses, or building up instead of out (we assert the importance of urban ecosystems in Module 8).

There may be a key link between armed conflict and the presence of biodiversity: one study found that 90% of the major armed conflicts that occurred between 1950 and 2000 occurred in countries rich in biodiversity, and 80% of these conflicts took place directly in biodiversity hotspot areas (Hanson, 2009). Even protected areas may also intensify potential conflicts with resource extraction. Here we encounter the problem of biodiversity offsets: if an ecosystem in one place is destroyed for resource extraction, can companies offset the associated loss of biodiversity by investing in the conservation of natural ecosystems of similar biological value elsewhere? In theory, this sounds like a great idea. In practice, some of the problems with this idea are (1) leakage, (2) measuring biological value for ecosystems and local people, and (3) identifying areas of equal biological value.

Depending on which IUCN category they fit into, protected areas may exclude local stakeholders, small-scale resource extraction, and traditional uses. Protected areas can be managed in a hierarchical way, which often involves the exclusion of local stakeholders, but, to better address the issue of local stakeholder exclusion, they can also be managed collaboratively (co-governance, as in the Integrated Conservation and Development Programs or ICDPs in Tanzania) or governed by indigenous peoples or local stakeholders (self-governance, as in Indigenous Peoples' and Community Conserved Areas and Territories or ICCAs in Nepal). Adaptive management/governance and stakeholder involvement are crucial to the success of ICDPs and ICCAs as both conservation and development tools.

Case Studies

Bats and Biodiversity

Many case studies illustrate the wicked problem of biodiversity decline, as well as the importance of genetic diversity to resilience. The insectivorous little brown bat (*Myotis lucifugus*) is native to Southern Canada and the Northern United States, and feeds on insects including mosquitoes and agricultural pests. It has been estimated that one little brown bat can eat 4-8 g of insects a night (Anthony & Kunz 1977, Kurta et al. 1989). They therefore provide a pest control service to humans. Insectivorous bats provide $3.7 billion USD in insect control services just to the agricultural sector in the United States every year (Boyle et al. 2011).

Unfortunately, the little brown bat has experienced rapid population decline over the past decade; it has thus been listed as endangered in Canada and in several U.S. states. Populations have declined by up to 94% in some areas. Although wind turbines are one cause of population decline in this species, the main cause of population decline is White-nose Syndrome (WNS), a fungal infection caused by the pathogen *Pseudogymnoascus destructans*. This fungus, first noted in North America in 2006, may have been introduced from Europe by humans (Frick et al. 2010). It affects bats during hibernation, causing them to wake up prematurely in the winter, and often leading to starvation or death due to lack of water. Up to 100% of all bats in an affected hibernaculum are killed (Rusell et al. 2015). Thus, human activity may lead to the loss of billions of dollars in pest control services through its effects on bats.

However, a glimmer of hope has recently been discovered for the little brown bat. Some colonies appear to be unaffected, even if they are found in areas where the syndrome has been detected (Dobony et al. 2011). It is unclear why some of these colonies appear to be resistant, but one possibility is that there is a precluding genetic factor. In other words, in this case, genetic diversity may allow for some individuals and colonies to survive the infection or even be unaffected while others die. Although models do not predict that this resistance will result in the rapid recovery of the species to pre-WNS levels (Russell et al. 2015), it is possible that species will recover over time, dominated by bats resistant to WNS. If this is the case, genetic diversity will have resulted in the resilience of the system.

Olive Ridley Sea Turtles in Costa Rica

The second case study illustrates a successful Integrated Conservation and Development Program, that of the Egg Harvest Program in Ostional, Costa Rica on the sustainable use of olive ridley sea turtle eggs. Sea turtle eggs have long been valued as food and for their supposed aphrodisiac qualities. However, since sea turtles are threatened across the world, it is illegal in most places to harvest their eggs. By the mid-1980s in Costa Rica, this situation had led to a lucrative illegal trade in turtle eggs (Campbell 1998).

The tiny community of Ostional was blessed with many turtle eggs and yet no way to benefit from them legally. The nearby Ostional National Wildlife Refuge protected a very productive *arribada*, an event that occurs monthly when hundreds of olive ridley sea turtles come ashore to lay their eggs. These events last several nights, each turtle crawling out of the water to dig a hole in which to lay dozens of eggs. The eggs must be buried at just the right depth: close enough to the surface to stay warm, but not too close, lest they are baked by the sun. The adult turtles do not stick around to make sure their eggs are protected, so, with so many turtles laying their eggs on the same beach, the eggs laid on the first or second nights tend to be buried by the turtles arriving later to lay their eggs, and therefore these early eggs tend not to hatch (Cornelius et al. 1991).

Members of the community banded together in the early 1980's to petition the government to allow them to legally harvest the eggs laid on the first night. In return, the community vowed to protect the rest of the eggs and young from harm, seeing the predation-prone hatchlings successfully back to the sea. What emerged was the successful community-based Egg Harvest Program, under which the community is allowed to legally sell certified olive ridley eggs at a government-set low rate in exchange for their protection of the remaining eggs and hatchlings (Campbell 1998).

This program has multiple benefits. It has brought the community out of poverty, providing a legal source of income. It has dealt a serious blow to the illegal trade in turtle eggs, since poachers can no longer sell their eggs at exorbitant rates given the competition of the government-set low rate of certified eggs from the Ostional Egg Harvest Program (Campbell, et al. 2007) . Finally, although it is difficult to assess the population status of sea turtles because they travel over such large areas of the sea, further research has supported the idea that high nesting density results in low hatchling success (Honarvar et al. 2011) and the Ostional Egg Harvest Program does not seem to be having a negative effect on populations of olive ridley sea turtles (Valverde et al. 2012). Although the program is not without its challenges, it does appear to have been a success thus far in terms of both biodiversity conservation and social-economic goals (Campbell et al. 2007); providing the ocean ecosystem in which they survive does not collapse, the turtles will have a brighter future with this unique human intervention.

Discussion points

1. How can biodiversity be valued socially, economically, and ecologically? Can you think of examples that lead to a systems thinking approach that emphasizes the value of biodiversity?
2. Does the concept of a keystone species reinforce or disengage from the ecosystem approach? What is the educational merit of focusing on keystone species?
3. Find an example in which there is conflict between biodiversity conservation and social and/or economic values. How could this conflict be resolved?
4. Take a quick survey of the biodiversity that can be found in your local community. Can you identify any keystone species, and do you see any emerging threats to its continued existence?

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Cavero, M. and Garcia -Berthou, E. (2005). Invasive species are a leading cause of animal extinctions. *TRENDS in Ecology and Evolution*,*20*(3), 110-110. *This paper criticizes the Gurevitch and Padilla paper, finding that invasive species are a major cause of extinction, especially for birds, fish, and mammal*

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Recommended websites

This ed.ted talk discusses the importance of biodiversity (ecosystem services and keystone species): http://ed.ted.com/lessons/why-is-biodiversity-so-important-kim-preshoff#watch

See the short article at the following link for more examples on how specific species can shape ecosystems (suitable for an entry-level university course): https://strangebehaviors.wordpress.com/2015/01/30/bears-nosh-on-ants-and-that-makes-everything-different/#more-7264

This TED talk discusses the importance of biodiversity: http://www.ted.com/talks/ameenah_gurib_fakim_humble_plants_that_hide_surprising_secrets

The Convention on Biological diversity website has information about biodiversity and conservation programs across the world: https://www.cbd.int/

The IUCN webpage lists species and ecosystems at risk across the world and includes information about causes of population declines: https://www.iucn.org/

The *Washington Post* has a good, accessible story about resistance to white-nose syndrome among some bat colonies, a good example of the importance of genetic diversity in conferring resilience (https://www.washingtonpost.com/national/health-science/little-brown-bats-found-that-appear-to-resist-disease-that-has-devastated-species/2011/12/21/gIQAwJD99O_story.html)

UNEP has a useful video on the importance of biodiversity at http://www.unep.org/flvPlayer/videoplayer.asp?id=978&l=en

Marla Spivak talks about the importance of bees to our food supply and the importance of a diversity of flowering plants to bees in here TED talk at https://www.ted.com/talks/marla_spivak_why_bees_are_disappearing#t-410673

The Terralingua Project website has useful information about biocultural diversity, i.e., the links between cultural and language diversity (http://terralingua.org/)

A useful video about keystone species can be found at the following link: https://www.youtube.com/watch?v=_IWw8Ruz8Uo

The following video is useful in presenting the main threats to biodiversity: *https://vimeo.com/25188228*

Details on the IUCN list of threatened ecosystems can be found at the following link: https://www.youtube.com/watch?v=g4coX3oWjs0

An example of a successful ICDP in Tanzania can be found at https://www.youtube.com/watch?v=NrUqb67Hs0k

More information about ICCAs can be found at http://www.iccaconsortium.org/?page_id=52

Module 5: Forests

Expected Learning Outcomes: upon completion of this module, students will be able to:

- Provide a definition of a forest and understand that there are many definitions
- Explain why forests are important in terms of the ecosystem services they provide and in terms of human well-being
- Understand that forests are complex adaptive systems, i.e., how countless interactions across temporal and spatial scales lead to emergent properties
- Understand the implications of forest loss and degradation
- Understand that forest loss and degradation are wicked problems

- Identify the strengths and weaknesses of various types of forest management and governance, including
    - The role of adaptive management and adaptive governance
    - The role of forest certification programs in encouraging sustainable forest management and the management of forests for greater resilience
    - The strengths and weaknesses of REDD+ programs in addressing the wicked problem of forest loss and degradation
    - The potential roles of adaptive co-management and community-based forest management (strengths and weaknesses)

Forests: the Iconic Ecosystem

It may well be the case that the image surfacing to mind when someone mentions "ecosystems" is that of a forest. This inclination makes historic sense: many people live in areas that were once heavily forested, across Europe, Asia, and North and South America, and one of the most famous environmental campaigns in recent decades has been the effort to save the rainforest. Many students will have fond memories of playing in forests as children; some will recall working in them. The link between forests and human well-being is firmly established and though we have destroyed many forests to build cities, farms, highways, and other anthropogenic structures, forest conservation has also become an international priority today.

The word 'forest' has many definitions. According to the Food and Agriculture Organization of the United Nations (FAO, 2000), a forest consists of land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use. Forests currently cover around 30 percent of the Earth's landmass, approximately 4 billion hectares.

Forest ecosystems comprise the relationships between forest plants and other organisms with which they interact in various ways (e.g., dispersal, predation, competition, and facilitation: note that forests provide habitat for numerous plants, animals, fungi, and other organisms), and between forest plants and the abiotic environment (e.g., water and soils). There are several different types of forest biomes (forests sharing similar characteristics due to latitude, terrain, altitude, and climate). Broadly, these include **tropical forests, temperate forests and boreal forests**, with several subdivisions within each biome (Begon et al. 2006).

Global **deforestation** is taking place at an alarming rate – evidenced in the decline in natural forest cover of 13 million hectares per annum during the period 1990-2005 (FAO 2012). The main drivers of deforestation are unsustainable practices, including intensive farming, human settlements and illegal logging. Although the rate of deforestation is slowing down, large areas of primary forest and other naturally regenerated forests are declining, especially in South America and Africa. Forest degradation is also increasingly problematic. Although variously defined, definitions of forest degradation generally involve a persistent loss of carbon storage and sequestration capacity and other services and functions of a forest in an area still technically defined as a forest. Forest degradation is mainly driven by small-scale, subsistence activities like gathering wood for charcoal and as firewood. Thus, as we will see in the case study on Haiti, the indirect driver of forest degradation is poverty, itself linked to unequal power relations and authoritative rent-seeking governments: in other words, a typical wicked problem.

This is highly unfortunate, because humans depend on forests in many ways. Benefits to humans provided by forest ecosystems include supporting services such as nutrient cycling, primary production, and biodiversity habitat, and regulating services such as windbreak and erosion control through the retention of soils by roots, water storage and filtration, waste treatment, and climate regulation. For example, trees and other plants remove carbon from the atmosphere and release the oxygen that we breathe via the process of photosynthesis, converting atmospheric CO_2 to biomass that is stored in all parts of the plant in a process called carbon sequestration (Evert and Eichhorn 2013). Forests store 25 percent of terrestrial carbon - this natural carbon sequestration mitigates the effects of climate change, by slowing the accumulation of a greenhouse gas in the atmosphere. Together, it has been estimated that deforestation and forest degradation account for 17% of greenhouse gas emissions every year (IPCC 2007). This is more than the entire transportation sector; only the energy sector results in greater annual emissions (IPCC 2007).

Forests offer provisional ecosystem services in a number of ways. Many parts of forest trees are harvested as natural resources, most importantly as timber, but also as non-timber products including bark, resin, and sap, as well as mushrooms, berries, and other food, cultural, and ornamental resources that do not necessarily come directly from trees. The global trade in timber and other forest products is estimated at almost US$330 billion per year. An estimated 1.6 billion people rely to some extent on forests for their livelihoods (World Bank 2008), while more than 2 billion people use biomass fuels, mainly firewood, to cook food and to heat their homes (World Health Organization 2016). In many developing countries, more than 80 percent of total energy consumed comes from forests and related biomass (Trossero 2002. Forests also provide cultural services such as recreation and ecotourism, in addition to having aesthetic and spiritual value for indigenous and other peoples. Trade in forest products contributes to material wellbeing by supporting local economies and sustaining the livelihoods of many people, as do associated recreation and ecotourism.

Forests support relational wellbeing, providing a setting for social interactions from traditional hunting and gathering to hiking, cycling, and other outdoor activities. In some traditional cultures, specific parts of the forest or even specific forest trees are used for specific social, cultural, and political purposes, some for ceremonial purposes, others as social meeting places, still others as places where the elders gather to make decisions and to consult with the community (e.g., Niangoran-Bouah 1983, Visser 1975). Forests also contribute to subjective wellbeing, through spirituality and in terms of individual physical and mental health. Many traditional cultures see forests as the link between the ground and the sky, between the spiritual world and the material world (see Calame-Griaule 1969, 1970). Binet (1974), for example, describes how the *Tabernantha iboga* tree in Southern Camaroon is thought to provide the means through which people can communicate with the gods.

A forest can be seen from various spatial and temporal scales. The main spatial scales generally considered are the tree (or individual) scale, the stand (or community) scale, and the forest (or population) scale. A stand is a contiguous group of trees approximately equal in canopy height, with the canopy trees (i.e., the tallest trees) of generally the same age. A forest is a group of relatively contiguous stands. At the stand and forest scales, structure and composition are important descriptors. Composition is the plant species present at that scale, sometimes described by only the most dominant tree species. The structure of a tree refers to its physical properties, including the age structure of the tree, the size of the stand or of the forest, and the degree of fragmentation or disturbance. Disturbance occurs frequently, and can damage individual trees or physically break apart a forest; types of disturbance include logging and road construction, fire, insect outbreaks, or fluvial processes such as water, ice, and wind damage (Johnson and Miyanishi 2007).Various physical and ecological processes occur at each scale; the cross-scale interactions result in emergent properties such as species composition and age of the forest.

For example, at the single-tree scale, water cycling (i.e., precipitation and evapotranspiration) and nutrient cycling (e.g., carbon and nitrogen) are important processes; the amount of light, water, and nutrients available will determine the survival of each individual tree (Waring and Running 2007), as will numerous other factors such as the susceptibility of the tree to insect damage or its appeal to humans as a source of timber. At the stand scale, community dynamics such as competition between trees for light, water, and nutrients determine which trees will survive, as well as how they will grow. This may also be affected by processes such as seed dispersal, which may be determined at the larger spatial scale of several stands or of an entire forest (Cousens et al. 2008). For example, in the case of seed dispersed by animals, conditions around the stand must be such that the necessary animal is likely to pass that way; often this means that there must be a sufficient area of forest to provide habitat for these animals.

The structure and composition of the forest itself is determined by processes that occur at the single tree and stand scales, but also at larger scales, such as the scale of global markets, which may affect whether the tree, stand, and forest are harvested for timber, for example. At all scales, the forest will change and adapt, in other words, self-organize in response to certain disturbances. If light is cut off from one side of a tree, the tree will grow in the other direction. If an insect attacks all the trees of a given species in a stand, trees of the other, non-target species will grow to fill the space left by those trees damaged or killed by insect attack. If a forest fire or logging operation affects an entire forest, the forest will likely grow back if allowed to do so, although the structure and composition of the forest may be somewhat different from before. Thus, a forest is a complex adaptive system characterized by emergent properties, numerous interactions across scales, and self-organization. As in other complex adaptive systems, forests may be characterized by resistance and resilience.

The example of the Jack pine (*Pinus banksiana*) and the trembling aspen (*Populus* tremuloides) is useful to explore the concepts of resistance and resilience. These species of trees are typical of the Western North American boreal forest. The Jack pine is not at all fire tolerant. In fact, it is quite flammable, meaning that it is not resistant to fire. However, a Jack pine stand is resilient to fire. Jack pine has serotinous cones, i.e., cones that release seeds only when subjected to the high temperatures of crown fires (Fenner and Thompson 2008). Thus, following a fire, a Jack pine stand will regenerate, demonstrating resilience to fire. On the other hand, if a Jack pine stand is cut down, it will not grow back on its own since logging does not involve the high temperatures necessary to release the seeds held within the fallen cones. Jack pine is not resistant to logging either, as it is valued for lumber and pulp! On the other hand, aspen is relatively resistant to fire; an aspen tree will not burn as easily as a Jack pine tree, and thus an aspen stand will not burn as easily as a Jack pine stand. However, it is not resistant to logging, since it is likewise valued as a source of timber and pulp. It is resilient to both fire and logging, however: since aspen resprouts easily from stumps and roots, it will grow quickly following any disturbance, even after a calamitous fire. Thus, both Jack pine and aspen are resilient to fire, although only aspen is resistant. Neither is resistant to logging, but aspen is the only one of the two tree species to be resilient to logging.

Towards adaptive governance of forest ecosystems

Calls for sustainable forest management have been heard world-wide for almost three decades since the 1992 United Nations Conference on Environment and Development adopted its Forest Principles specifying the need for forest management that provides for "the social, economic, ecological, cultural and spiritual needs of present and future generations" (United Nations General Assembly 1992). Since then, criteria and indicators of sustainability have been developed and the principles of sustainable forest management have become entrenched into laws and regulations across the world. These principles have been equally embraced by major forest certification bodies (e.g., the Forest Stewardship Council Standards: FSC), which encourage sustainable forest management through market-driven mechanisms.

However, rapidly changing global conditions (climate, market, etc.) demand current concepts of sustainability be expanded to include notions of resilience whereby forests are recognized as dynamic social-ecological systems that will inevitably be affected by disturbances of unknown nature and magnitude. Under such uncertainty, we must manage forests in ways that maintain the functions and services on which we depend, both at local and global scales (e.g., Millar et al. 2007). Managing forests as complex adaptive systems, thus integrating ecological, social, and economic values may provide a means to maintain sustainability and resilience (Messier et al. 2013 and 2015). To do so, some type of adaptive governance, using an ecosystem approach, is crucial. Such a structure allows for the inclusion of stakeholders in the process, as well as the monitoring, assessment, and periodic reformulation of management practices; it is the best way to provide for the needs of today without compromising the ability of future generations to meet their needs (including providing habitat for biodiversity), thus meeting the main goals of sustainable forest management.

The inclusion of local stakeholders in the management and government processes is crucial to ensure that the needs of these stakeholders are met, but also to ensure that traditional and local ecological knowledge is included in guiding these processes. Such knowledge provides a more complete picture of the system, often filling in holes where scientific knowledge is lacking. However, there is often no written record of such knowledge, so if it is to be included, local and indigenous peoples must be involved in the processes.

One attempt to govern forests such that global and local needs are balanced against the needs of future generations is REDD+. The main goal of this program is to slow or stop deforestation and forest degradation in developing nations by minimizing poverty, thus benefitting not only local people but the global community by maximizing the carbon sequestration and storage ability of the forest and hopefully regulating anthropogenic climate change. The other goals of REDD+ are conservation, sustainable forest management, and enhancement of forest stocks as goals. REDD+ programs provide funding from wealthy nations in the north to forest-dependent people in developing nations so that they will be able to preserve their valuable forest rather than destroying it through poverty-driven practices that result in forest degradation and deforestation. Such programs face multiple challenges, from assessing and monitoring the carbon storage capacity of the forest to making sure the money goes to the people who stand to lose from changing their use of the forest in favour of conservation. Stakeholder involvement at all levels is crucial here, but may be particularly difficult to maintain at local levels. However, the idea of managing the forest in a collaborative way for the good of all by addressing poverty, one of the wicked problems underlying causes of deforestation and forest degradation, is laudable.

In many parts of the world, **community-based forest management** is being applied as a way to manage the forest sustainably. The assumption behind this type of management is that local communities, concerned for their present situation as well as for their future and for the future of their children, will manage the forest in a sustainable way, recognizing that their quality of life is dependent on its continued existence. Through an adaptive approach, such systems have met with moderate success in some areas (e.g., in Nepal, see Thoms 2008) but are also sometimes plagued by a lack of funding, expertise, and available resources, as in Lao People's Democratic Republic (Fujita 2008), and by stakeholder conflict, as in Honduras (Nygren 2005).

Adaptive management programs involving multiple stakeholders have also met with some success, notably in the Pacific Northwest of the United States (Bormann et al. 2007). Here, multiple management strategies are applied simultaneously on different parts of the forest, progress is monitored, results are analysed, and adjustments are made to the management plans on a periodic basis based on the results of the monitoring. However, adaptive management approaches do not necessarily involve the stakeholders necessary to assure that the needs of current and future generations are being met.

Adaptive co-management is an attempt to put it all together: to include stakeholders at various levels (local, regional, national, etc.) in an adaptive management-type format that has communities and governments managing the forest together. Here, as elsewhere, it is challenging to ensure proper representation of all stakeholders in the process, as noted by Cundhill in his studies in South Africa (Cundhill 2010). It is a key goal of UNEP to support an integrated approach to encourage stakeholder consultation and cross-sectoral dialogue.

The dominant **forest certification programs** of the world generally require some type of adaptive management or governance structure, involving local stakeholders, monitoring, and periodic assessment of progress and an ecosystem approach. Forest certification programs are market-driven programs through which forest industries are certified by a third party based on pre-determined standards. These programs depend on a market for certified products; if consumers show no interest in paying more for products that are certified as sustainably produced, there is no role for certification programs.

However, at present, there is a relatively large market for certified products, so forest certification programs like the Forest Stewardship Council and the Program for the Endorsement of Forest Certification hold some power. Unfortunately, certification is generally quite costly to obtain, so tends to go to the wealthy, giving them an unfair advantage on the global market.

Despite the best of intentions, certification may increase the poverty gap, thus failing to curb deforestation and forest degradation in developing countries (Rametsteiner and Simula 2003). This is an example of a well-meaning attempt to address the wicked problems of deforestation and forest degradation that has had unintended negative consequences, increasing rather than reducing the poverty gap.

Case studies

Deforestation in Haiti

Haiti has long been plagued by extreme poverty. To feed themselves and their families on a daily basis, much of the population is dependent on wood from the forest. But combined with logging during various periods of Haitian history and a troubled governance structure, this situation has led to extreme deforestation and forest degradation in the country. Less than 2% of Haiti's land is now forested; reforestation efforts have largely been sabotaged due to the high demand for wood. Since forests protect against soil erosion and floods, this deforestation and forest degradation has in turn made living conditions even worse for local people, as topsoil crucial for food production is washed away and flooding is common, leading to extreme food shortages, landslides, destruction of roads and homes, and further deterioration of the general health and well-being of the population. Threat of desertification is imminent, another cause of deforestation, since trees are no longer there to reduce air temperatures and increase moisture levels through evapotranspiration. Combined with the calamitous earthquake of and other natural and political instability, Haitians have had a hard time advancing human development.

This is a classic example of the wicked problem of deforestation and forest degradation, of which poverty and inequity is both a driver and a consequence. Some would argue that the only way out of this cycle is through foreign investment. In the community of Petit-Goâve, locals have collaborated with international experts from the IOM (International Organization for Migration, an intergovernmental organization) to carry out a nursery, reforestation, and sustainable forest management project in the mountains above the village. This increased water availability; with the construction of communal irrigation canals, it became possible for villagers to grow food in the valley. With the money from sustainable forest management and food production, villagers are now able to send their children to school, no longer starving, and the forest continues to grow and regenerate. The UNEP maintains an active presence in Haiti, contributing to the pursuit of sustainable development. See http://www.unep.org/disastersandconflicts/CountryOperations/Haiti/tabid/104691/Default.aspx

Co-management in Honduras

In Lepaterique, Honduras, there has been true community-based management. The municipality of Lepaterique includes over 15 000 residents, mostly of native Lenca descent (Nygren 2005). It is a fairly poor community; approximately a third of the population is thought to be illiterate ((PNUD 2002, cited in Nygren 2005). Forestry operations here, as elsewhere in the country, have traditionally been centralized, dominated by large timber companies from outside the community, thus excluding local residents from the management of their forests and from the financial profit associated with this management. However, in the 1990s, forest ownership was given to the municipality. The community then worked out a management plan, which included access to forest resources for local timber companies, resin tapping, charcoal collection, collection of resources for ornamental purposes, and firewood, as well as excluding protected areas from resource extraction. The management plan also eliminated access to companies from outside the community (Nygren 2005).

The Lepaterique program has been largely touted as a success (Ferroukhi 2003). For the first time, residents have set up forestry companies, which now account for two thirds of the municipal budget. Households involved in these companies doubled their incomes, and forestry workers began earning twice as much as agricultural workers (Nygren 2005). Unfortunately, since the municipality now requires some payment up front for logging operations, only the wealthier residents can afford to get into the forestry business. By 2004, the nine operators dominating the logging operations had made a clandestine agreement with the outside timber companies to sell them wood in return for loaning them the money for the up-front payment (Nygren 2005). Thus, although much of the profit still remains in the community, it is not necessarily equally distributed, and some of it does not stay in the community. This system of dominance by the forestry industry also puts other users of the forest resources at a disadvantage.

There is, for example, conflict between the resin tappers and the loggers, the tappers claiming that a pine tree can be fruitfully tapped for two or three decades, the loggers arguing that to do so for more than 8 years damages the quality of the timber. There is also an associated push to tap the trees for resin in a less effective way, thus reducing both the amount of resin obtained and the potential damage to the timber by drilling one large rather than several small holes in the tree. Resin tappers claim to manage the forest in a more sustainable way, while loggers argue that the forest is a resource to be exploited and farmed. There is also conflict between the charcoal producers and the resin tappers, with the former lighting fires for their purposes while the latter protect from fires (Nygren 2005). These are all issues that must be worked on, indicating that community-based management is still complex. However, despite the conflicts, the devolution of forest management to the community level has resulted in greater local access to the forest, to more sustainable management, and an improved standard of living for many (Nygren 2005).

Discussion points

1. What does “the forest” mean to you? Do you think it means something different for you than it did for your grandparents or great-grandparents? Why?
2. Can you think of a case in which stakeholder involvement might not be important for forest management? Why or why not?
3. What would the world be like without forests? Would humans survive?
4. Should forests on private lands be managed differently from those on public lands? Why or why not?

Annotated Bibliography

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Recommended websites

The website of the Food and Agricultural Organization of the United Nations (http://www.fao.org/themes/en/) has a multitude of information on forests, forest management and governance, and statistics, including links to the latest Global Forest Resource Assessment report.

Infographic of forest ecosystem services (http://www.fao.org/assets/infographics/pdfimg/FAO-Infographic-ForestFarmFacility-en.jpg)

Infographic "Photosynthesis" (https://spierssciencetalk.files.wordpress.com/2013/10/jgjffjf.jpg)

Infographic "The root of the problem" on carbon sequestration and climate change (http://photos.the-scientist.com/legacyArticleImages/2011/08/From-The-Ground-Up.jpg)

Details and links to more information on REDD+ are available at http://www.un-redd.org/aboutredd

A short video on deforestation and forest degradation in Haiti is available at the following link: https://www.youtube.com/watch?v=kLmpFHSsGD0)

A short video on the reforestation efforts in Petit-Goâve, Haiti is available at the following link: (https://www.youtube.com/watch?v=4VEdzoKXS5Y

Module 6: Fluvial Systems

Expected Learning Outcomes: upon completion of this module, students will be able to

- understand how water and sediments are transported from the upstream parts of the

watershed to the mouth. This will include understanding basic fluvial processes, including lateral meander migrations, recurrent flooding, and the formation of floodplains. Examples will include Amazonian migration, and Nile flooding
- discuss the ways in which fluvial systems contribute to ecosystem health and biodiversity in the rivers, riparian zones and beyond (e.g. the introduction of wolves in Yellowstone National Park)
- understand how the processes introduced above lead to dynamic equilibrium and what this means for different fluvial scales and environments
- describe different kinds of human interventions, and how they affect fluvial systems. Students will recognize the impacts of such interventions as the straightening of the Mississippi River in the United States, and the construction of the Three Gorges Dam in China
- gain an understanding of how climate change will affect fluvial systems, and the importance of increasing resilience by integrating more natural processes in river management

Components of fluvial systems

Water is one of the primary sources of life, and we can all relate to its immense importance in our daily lives, regardless of where we live. However, students and other consumers do not often appreciate the systems complexity of water usage and the natural ecosystem services related to water. Asking students where their water comes from, and how it is treated before and after they use it, often results in blank stares. Few of them realize that water comes from the hydrological cycle, itself a continuous system; or that fluvial systems shaped by both nature and humans provide the bulk of drinking and cleaning water to most communities.

Freshwater ecosystems and natural and anthropogenic fluvial systems provide food, employment, cooling systems, recreational use, and many other human needs. And yet, many regions are in danger of (or are experiencing) serious water shortages due to overuse, chronic drought, climate change, water contamination, and other wicked problems demanding dynamic, collaborative solutions. When solutions cannot be found, conflict is often the result, though dire predictions of widespread water wars have given way to a more subtle appreciation of the possibilities offered by collaboration. This module introduces students to the basics of fluvial systems, including watersheds, drainage networks, rivers, streams, lakes, and wetlands (we cover oceans and coasts in a separate module).

In 2010, access to clean drinking water became an official basic human right. A resolution introduced by Bolivia was adopted by the UN General Assembly without opposition. Although the decision does not make the right to water legally enforceable, it is symbolically important and places more political obligations on national governments. The combination of rising water scarcity due to increases in demand and the potential consequences of climate change make the need for cooperative, equitable and sustainable management of fluvial systems more important than ever.

The basic component of a fluvial system is the **watershed**, a drainage network of rivers, streams, lakes and wetlands through which water flows. Over time, the deposition and erosion of sediments within these water bodies shape the landscape (creating floodplains, valleys, etc). It is important to be aware of these interacting components and processes (their system complexity) in order to properly understand the ecosystem services fluvial systems provide, and the impact of human interventions on system health and resilience.

As we have stressed throughout this course, in a system, some parts are affected by changes in the composition of other parts, often as the result of human decisions made elsewhere. This is readily apparent within **the system dynamics of water flow**: the flow dynamics of water and sediment transport interact to create a complex fluvial system of deep pools, shallow riffles, erosion and deposition which leads to the lateral migration of river meanders, which in turn create wetlands and widen floodplains (we offer a Google Earth Engine animation in this module to demonstrate this). Though fluvial systems may experience a **regime shift**, for example an abrupt change in the course of a river due to increased bank erosion, it will not necessarily reach a tipping point like other systems might. Rather, the system will reach a new equilibrium following a disturbance, meaning that it will adjust its dimension (width and depth) or slope (change in sinuosity) to accommodate for the change (e.g.: changes in discharge and/or sediment load). This natural balancing act is often disrupted by human intervention, of course, especially by the construction of large dams and other objects that disrupt natural water flows driven primarily by gravity.

Rivers provide **ecosystem services** that are crucial for human, animal and plant survival and wellbeing. They provide material wellbeing in the form of drinking water, food (fish and other aquatic animals), and a diversity of vegetation. They also provide relational and subjective wellbeing by providing the nutrients necessary for the creation of highly fertile soils in the floodplains, which, for this reason, have historically been centers of human populations. It is likely that there is major river system in the country where you live that has shaped the course of local human history, and major river systems (such as the Nile, the Rhine, the Amazon, the St. Lawrence, the Mekong, and others) have shaped national and even global human affairs. Moreover, rivers and their system dynamics can be central to cultural evolution of societies and religion; for example, the Ganges is sacred to the Hindu population of India. Finally, rivers provide spaces for various recreational activities such as swimming, skating, or boating, which can also provide well-being, physical activity, and relaxation.

Thus, rivers provide an important space in which civilization and cultures have thrived, evolved, and eventually collapsed. **Floodplains**, for example, have been central to human settlements across the ages. Floodplains are formed on either side of a river due to recurrent flooding, and they are widened and shaped by the meandering of rivers, a result of their dynamic behaviour. These processes bring with them the sediments and the nutrients from the river, creating highly fertile soils in the floodplains. Since the dawn of agricultural technology, humans have settled on floodplains such as the Fertile Crescent (shaped by the Tigris and the Euphrates), the Nile River Valley in Egypt, and the Mekong Delta in southeast Asia.

Today, urban settlements have also developed in these floodplains, including megacities that continue to grow and benefit from the ecosystem services provided by rivers. The Yamuna River, a main tributary of the Ganges River has been central in the history and culture of Delhi, and contributed to its status as the capital of India because of the ecosystem and transportation services it provides. Nor would Montreal have become a major cosmopolitan city were it not for the transportation, wildlife, and nutrients provided by the mighty St. Lawrence River. Further, many industrial and agricultural activities make extensive use of rivers and lakes as sources of freshwater as well as dumping basins for pollution and excess nutrients such as nitrogen and phosphates.

Beyond the damage industrial, sewage, and agricultural practises cause to freshwater sources, our reliance on rivers and floodplains come at another cost: vulnerability to the vicissitudes of changing river system dynamics, such as flooding and the lateral migration of meanders. Historically, engineers have employed a range of hard interventions, including channel straightening, bank stabilization, and the construction of dams and levees. These interventions have favoured the well-being and protection of human settlements and commercial activity, rather than focusing on ecosystem health and resilience and the long-term services provided by these ecosystems. However, following the relative failure of this approach (e.g. the 1993 Mississippi flooding) there has been a recent move to integrate natural processes into river management to enhance ecosystem resilience and shift towards more long term, sustainable goals. This conceptual and physical transition demands the application of an ecosystem approach that benefits from systems thinking.

Managing transboundary water resources (rivers, lakes, coasts, aquifers, and other water sources that cut across national boundaries) is especially challenging. At present, there are 263 rivers that either cross, or demarcate, international boundaries. To date, shared water resources have more often been the stimulus for co-operation than for conflict. Giordano and Wolf (2002) observe that “cooperative interactions between riparian states over the past fifty years have outnumbered conflictive interactions by more than two-to-one. Since 1948, the historical record documents only 37 incidents of acute conflicts (i.e., those involving violence) over water (30 of these events were between Israel and one or another of its neighbors, the last of which occurred in 1970), while during that same period, approximately 295 international water agreements were negotiated and signed” (see Stoett, 2012, for further discussion). However, there are important qualifiers to this finding. They go on to observe that “158 of the world’s 263 international basins lack any type of cooperative management framework”, and that “of the 106 basins with water institutions, approximately two-thirds have three or more riparian states, yet less than 20 percent of the accompanying agreements are multilateral.” Even where trans-boundary management frameworks do exist, cooperation may still take place on an unequal basis, reflecting existing power and political economy dynamics. In addition, there is also the future effect of climate change to consider, which, as already noted, is likely to have particularly significant near-term impacts on water availability and predictability.

Responsive Initiatives

The shift from hard engineering practices in river management towards adaptive governance and management to increase fluvial system resilience is especially needed in the face of a changing climate. As such, management practices have begun "working with nature". One way in which this is possible is by restoring functional riparian zones along rivers, a practice known as "Freedom Space for Rivers" in Quebec, "Room for the River" in the Netherlands, "Making Space for Water" in England, "Fluvial Territory" in Spain, and the "Erodible Corridor" in France. This practice allocates space along the river on the floodplain for natural processes of bank erosion and flooding to occur. By restoring these riparian zones, natural filtration processes will help restore water quality, and by moving human settlements further away from rivers, the effects of flooding and bank erosion on human settlements will be muted.

Another type of adaptive management is the EEDS (eco-engineering decision scaling) method, which involves a careful examination of the management situation, and takes into account both engineering design features and the ecosystem services. Thus, this alternative is an ambitious mix between the hard engineering practices of the past, and complete river naturalization initiatives. As climate change brings increased drought in some areas and increased flooding in others, it more important than ever that we are able to plan ahead and restore the natural resilience and benefits of fluvial systems. Pollution control, the regulation of fishing and shipping, limited water intake, monitoring of fish and wildlife, and other policy interventions are vital as well.

Integrated Water Resources Management (**IWRM**) promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Although there are significant U.S. legal and jurisdictional barriers to IWRM implementation, there are several successful examples in North American basins. In 2012, the US Bureau of Reclamation completed a Colorado River Basin study that predicts a gap of 3.2 million acre-feet (~3.9 billion m3) between water supply and demand for the 2041–2060 period. The report identifies key complexities, uncertainties, and vulnerabilities that will need to be considered in addressing projected water shortages (USBR 2012a). Efforts are ongoing to develop decision support tools for IWRM in the Colorado River Basin (Alexander *et al.* 2013).

The Yakima Basin Water Plan provides another recent example of large-scale IWRM planning. The water supply in the basin does not meet the needs of dependent communities, which include irrigation demand, municipal supply, and the in-stream flow requirements of fish and wildlife. As climate change and population growth threaten to further shrink the snowpack and associated water supply, the water deficit is projected to worsen. A comprehensive planning effort was launched in 2009 that included representatives from: the Yakama Nation; irrigation district; environmental organizations; and federal, state, county, and city governments. The plan was finalized in 2012 and addresses fish habitat, modifications to the operation of existing structures, surface water storage, market-based reallocation of water, groundwater storage, and enhanced water conservation (USBR 2012b).

An on-going African example involving UNEP is the Tana Catchment Area in Kenya, which originates from two of Kenya's water towers (Mt. Kenya and the Aberdares), covers over 20% of the country's landmass, and delivers critical ecosystem services to millions of Kenyans, including 80% of Nairobi's water supply and 70% of the country's hydroelectricity (from five operational dams). Unsustainable land use and poor water management have seriously compromised the Tana Catchment Area's ability to provide these services, and the UNEP is working with Kenya's Water Resources Management Authority to build its capacity to effectively implement the Tana Basin Catchment Management Strategy. (See: http://www.unep.org/esm/Waterecosystems/Thematicareas/ManagingAquaticEcosystems/MarineProtectedAreasManagement/FreshwaterGovernance/TanaCatchmentArea/tabid/131723/Default.aspx)

It should not surprise us that access to freshwater plays a major role in the Sustainable Development Goals adopted by the UN General Assembly in 2015. Goal 6 calls for the availability and sustainable management of water and sanitation for all, and lists a series of specific targets:

6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
6.a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
6.b Support and strengthen the participation of local communities in improving water and sanitation management

There are few issues of such fundamental importance to daily survival than the provision of clean water. Students should learn about their own water sources: where the freshwater comes from, how it gets to them, and how it is treated before and after its use. Importantly, nature provides much of the freshwater on which we are dependent. Human interventions have changed fluvial systems since the dawn of civilization, and present efforts are often grandiose designs which create as many problems as they solve. Creative solutions to pursue greater benefits from freshwater sources while increasing resilience to climate change demand sustained systems thinking, including the human dimensions of change.

Case Studies

Wolf reintroduction in Yellowstone National Park

We don't normally think of wolves as river engineers, but the consequences their presence in one of the most famous parks in the world offers an interesting story. Wolves were eradicated from Yellowstone National Park in the United States in the 1920s. Without their biggest predators, deer populations rose rapidly, and park managers quickly became aware of the effect that this had on the ecosystem as a whole. Despite deer culling, the increasing number of deer were browsing trees and inhibiting their growth. Thus, the number of aspens, willows, cotton woods and alders was greatly reduced, and the landscape was altered.

In 1995, 14 wolves were introduced into the park, and in 1996, 17 more were introduced. This re-introduction lead to what is known as a **trophic cascade**, in which wolves limited the number of deer, but also changed their behaviour, leading to a number of biotic and abiotic ecosystemic changes (Ripple, Beschta and Painter, 2015).

The re-introduction of wolves led to a decrease in coyotes, which allowed for a surge in small herbivore populations including rodents and lagomorphs (Ripple and Beschta 2011). This increase in small prey then lead to an increase in avian predators, and land predators like foxes and badgers (Ripple and Beschta 2011). Moreover, the carcasses left by wolves provided food for scavenger birds and bears, whose numbers in the park also increased. As part of a positive feedback loop, the increase in bear populations lead to an increase in predation on elk calves, further decreasing the ungulate populations, thus promoting vegetation growth (Ripple and Beschta 2011).

There was also an important effect on woody plant species, such as aspens, cottonwoods, willows, and alders in riparian zones, whose growth was being limited by over-browsing (Beyer, Merrill, Varley and Boyce, 2007; Ripple and Beschta, 2007; Ripple and Beschta 2011). This provided a habitat for a range of bird species (Baril, Hansen, Renkin, and Lawrence, 2011) and, due to beaver preferences in wood types, an increase in beavers dams, which in turn positively affected fish, reptiles, amphibians, and aquatic mammals such as muskrats and otters (Ripple and Beschta 2011). This renewed riparian vegetation changed the course of streams and rivers in the park. Because of their roots, riparian vegetation create bank stability, which diminishes bank erosion and limits lateral migration (Beschta and Ripple 2012). Moreover, increased stability leads to a decrease in width, and thus a more complex pool and riffle morphology develops, thereby benefiting fish communities (Beschta and Ripple 2012).

In summary, the reintroduction of wolves in Yellowstone National Park after decades of absence proved to be beneficial for ecosystem health and the fluvial system providing the most vital ecosystem service to all denizens of the park. Wolves played a crucial role in decreasing the number of elk in the park, but their presence also changed the elk's behaviour. This had a cascade effect on the rest of the ecosystem, from vegetation, to aquatic and land animals, and other abiotic entities like streams and rivers. Even if there is still a scientific debate on the exact role of wolves in this ecosystem, in particular on vegetation (Marris, 2014), the reintroduction of wolves to the Park is a very good example of the complexity of ecosystems, their fragility, and their potential for resilience.

The Mississippi River

Human interventions on rivers, their benefits, and their shortcomings are perfectly exemplified in the Mississippi River Basin, and its historical development. Following European settlement of the Midwestern United States in the colonial period, vegetation cover in the Mississippi River Basin continuously declined (Turner and Rabalais, 2003). This occurred because the highly fertile soils of the floodplain served as prime agricultural locations. In fact, today, 65% of the land in the14 states that make up the Mississippi River Basin is farmland (Turner and Rabalais, 2003). As such, the decrease in natural vegetation and increase in farmland lead to an increase in soil erosion, and therefore a higher sediment yield in the Mississippi River, thereby changing its dynamic. However, Turner and Rabalais (2003) point out that intense farming and the use of fertilizers and pesticides affected the basin more than the first wave of conversion to farmland and pasture, in terms of sedimentation and river pollution by nutrients. Another important aspect of pollution in the Mississippi River is industrial waste (Turner and Rabalais, 2003).

Because the Mississippi River flows into the Gulf of Mexico, this has major effects on the health of the Gulf marine ecosystem, in the form of marine eutrophication and hypoxia (EPA, 2016; Mitsch, et al., 2001). Eutrophication refers to an increase in organic matter to an ecosystem, from both internal and external sources, due to an increase in nutrients (like nitrogen and phosphate from fertilizers). This has detrimental consequences on the water body including aquatic vegetation overgrowth and algal blooms. Eutrophication can lead to hypoxia, which refers to a depletion of dissolved oxygen in the water column to very low levels, which can cause stress of aquatic biota and death (NSTC, 2003).

Pollution is not the only aspect of the Mississippi River that makes it an archetype for human interventions in rivers. Indeed, the Mississippi is one of the most heavily engineered rivers on the planet, and with this has come a false sense of security that has proven costly for American society. The Mississippi River has undergone numerous engineering feats, including river straightening to expedite the flow by removing meanders, stabilizing channels, and the building of dams and levees along the river to protect communities living on the floodplains. The river has been shortened by over 330 km; 1400km of banks were stabilized; and over 3000 km of artificial levees were constructed (Kesel, 2002). This has changed the complex dynamics: the Lower Mississippi River was previously a depositional meandering river, which received its sediments from upstream, and fed the sediments to wetlands in Louisiana. However, due to human intervention, the river no longer receives its sediments from the floodplain (via bank erosion), resulting in land subsidence in the delta plain region of the Gulf of Mexico (Alexander et al., 2012). Combined with sea-level rise and storm surge, this is putting the coastal population at risk. Moreover, because of dyke blockages, sediment is no longer being fed to the wetlands, which has impacted their health and resulted in 25% loss in wetland area (Kemp, Day and Freeman, 2013; Kesel, 2002).

In 1993, the Mississippi flooded to an unprecedented level. The floods caused an estimated U.S.16 billion dollars in damage (Pinter, 2005). It has been said that flood control structures prevented 19 billion dollars in damage, but those estimates ignore the fact that navigational dykes and levees actually increased flooding (Pinter et al., 2008); of course, structures in the floodplains only exist because of the false sense of security created by human engineering (Pinter, 2005). The extensive system of levees and wing dykes, although providing protection from floods, has reduced overall channel capacity for high-magnitude discharges, causing increases in flood stage by up to 4 meters compared to the pre-modified state (Alexander et al., 2012). In fact, following the 1993 flood, there was a push towards relocating people that lived in high-risk areas. The Federal Emergency Management Agency (FEMA) spent 56.3 million dollars on relocating 7700 properties (Pinter, 2005). However, in more recent years, these positive initiatives have been counterbalanced by renewed development of property along the floodplains. Pinter (2005) states that FEMA does not require areas protected by levees which are designed to withstand a 100 year flood to even be marked on flood-hazard maps (a 100 year flood means a flood that has the probability of occurring once every 100 years; in other words, there is a 1% chance of a flood of that magnitude occurring any given year). In the face of a changing climate, the recurrence of 100 year or greater floods is expected to increase. Therefore, in countries which have the space and resources to do so, initiatives such as the Dutch 'Room for the River' fluvial corridor (Biron et al., 2014) are an excellent tool to prevent losses (and have been proven to be more economical than non-reaction (Buffin-Belanger et al., 2015).

However, there are countries in which this is more difficult. For example, the Ganges, the Brahmaputra, and the Meghna Rivers come together and form a delta in the Bay of Bengal in Bangladesh. Because of these three major rivers, a large part of the country serves as a flood plain. Each year, during monsoon season and subsequent flooding, around 25-30% of the country might be inundated (Islam, Haque and Bala, 2010; Penning-Rowsell, Sultan and Thomson, 2012). During more extreme monsoon seasons and subsequent flooding, 40-70% of the country might be inundated (Penning-Rowsell, Sultan and Thomson, 2012). Bangladeshi communities have adapted to annual flooding to a certain degree, but climate change is likely to increase the number of high intensity monsoon seasons, thereby increasing the intensity of floods and the ensuing fatalities, damages and costs associated with them (Penning-Rowsell, Sultan and Thomson, 2012). However, because of the high population density along these vast floodplains, limited space and limited resources, it will be a challenge for Bangladesh to implement erodible corridors along the rivers. Nonetheless, there have been recent discussions on adapting such practices to the Bangladeshi setting (Dione, 2014).

Discussion points

1. The effect of climate change will include more frequent high intensity precipitation events which will lead to increased flooding and vulnerability of human population living in floodplains. How can your community prepare for this possibility? Which actors, including property owners, will need to adjust their behaviour? What trade-offs between different forms of human well-being will be necessary to achieve greater resilience?

2. What hurdles will governments face in implementing adaptive water management plans (e.g. finding a balance between water as a common good, the need for food production, and farmers having to assume financial loss of crop space if riparian zones are extended in agricultural landscapes)?
3. What environmental injustices could some countries face in terms of bettering water quality through adaptive management practices? While the "global north" may have the funds to implement change (albeit unevenly), lower income countries continue to struggle to provide clean water to the population, and lack sufficient funding to better manage their fluvial systems and decrease vulnerability.
4. Can you identify the main components of the fluvial system that services your community or professional sector? What are the main challenges it faces?

Annotated Bibliography

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Florsheim JL, Mount JF, Chin A (2008) "Bank erosion as a desirable attribute of rivers." *Bioscience* 58(6):519–529 *This paper paper explains the positive impacts of bank erosion* *on fluvial ecosystems , and as a process that promotes healthy habitats. Thus, this article focuses on the ecosystem services of the river rather than the traditional purely economic views.*

Piégay H, Darby SE, Mosselman E, Surian N (2005) "A review of techniques available for delimiting the erodible river corridor: a sustainable approach to managing bank erosion." *River Research and Applications* 21(7):773–789. *This paper discusses the need to define a fluvial corridor that takes into account natural meander dynamics, showing how this would decrease erosion hazards.*

Poff NL, Brown CM, Grantham TE, Matthews JH, Palmer MA, Spence CM, Wilby RL, Haasnoot M, Mendoza GF, Dominique KC, Baeza A. 2016. "Sustainable water management under future uncertainty with eco-engineering decision scaling." *Nature Climate Change* **6**: 25-34 *This paper discusses water management and specifically flood mitigation (in the context of a changing climate) using a case study of the Iowa River, and uses the notions of ecosystems functions and services rather than simple economic factors.*

United Nations Environment Programme. *Early Warning and Assessment Technical Report: The Mesopotamian Marshlands: Demise of an Ecosystem* (2002), available from http://www.grid.unep.ch/activities/sustainable/tigris/report.php *This report is very interesting because it provides a history of the Mesopotamian region, and the current environmental struggles that the region is facing due to damming, drainage and pollution.*

Wang, Z.Y., Lee, J.H.W., and Melching, C.S. (2015). "River Ecology and Restoration. In *River Dynamics and Integrated River Management.* Beijing: Tsinghua University Press. *Provides examples for river restoration world-wide, including China, Germany, many countries in Africa, and Canada.*

Woo, H. "River Restoration." *Handbook of Environmental Engineering, Volume 15: Modern Water Resources Engineering,* 237-277. *A chapter which examines river restoration, but also provides basic concepts in the fluvial system discussed above.*

Yang, J. "Energy accounting for the Three Gorges Dam project: three scenarios for the estimation for non-renewable sediment cost." *Journal of cleaner productions, 112*, 3000-3006. *Another technical paper which outlines this method of calculation sedimentation costs, which dramatically lowers the sustainability index of the project*.

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Recommended websites

http://www.columbia.edu/~tmt2120/introduction.html
A concise summary offered by Columbia University of the Aral Sea disaster, one of the worst cases of fluvial system management that occurred in the former Soviet Union.

http://www.ted.com/talks/george_monbiot_for_more_wonder_rewild_the_world#t-507386
A video which outlines the effect of wolves on the entire Yellowstone ecosystem, including rivers.

https://www.youtube.com/watch?v=Fvkzjt3b-dU A very short video by the National Geographic which shows the importance of water.

https://www.youtube.com/watch?v=2pXuAw1bSQo Another very short video by the National Geographic on the same topic.

https://www.youtube.com/watch?v=WxereGwgJyU "A river runs through us": A 20 minute video about the importance of rivers and fresh water on well-being for people around the world, and how climate change and management practices like damming negatively affects people and the connectivity to floodplains.

https://vimeo.com/40519851
"Undamming the Elwha": A documentary that shows the negative effects of a dam on a river on the ecosystem (especially salmon), and the people that rely on that fragile ecosystem. The undamming of the river shows how systems can be restored even after decades of poor management.

http://www.theatlantic.com/technology/archive/2011/05/what-weve-done-to-the-mississippi-river-an-explainer/239058/ A very informative article on river straightening in the Mississippi River and the resulting problems.

https://earthengine.google.com/timelapse/ This link shows the lateral migrations of meanders in the Amazonian River basin in Bolivia (click "meander" on the tool bar)

http://study.com/academy/lesson/understanding-graded-streams.html
This link explains graded streams in a very simple and clear way.

https://www.youtube.com/watch?v=79H8aCWOq3U The Grand River (Missouri) example nicely illustrates how a river which had been straightened in the 1930s slowly adjusted its slope through a change in sinuosity, returning to a meandering platform.

Module 7: Oceans and Coasts

Learning Objectives: by the time they have completed this module, students will be able to:

- conceive of the global ocean as a dynamic body of water
- provide a general overview of the links between oceans and climate
- explain the importance of healthy oceans and coasts for current and future human wellbeing
- list major anthropogenic threats to oceans and coasts
- illustrate the process of ocean acidification and predict its impacts
- describe the current state of world fisheries and identify the main causes of fisheries collapse
- identify how the ecosystem approach and systems thinking can contribute to addressing the ocean and fisheries crises (e.g. moving away from single-species management)
- illustrate the links between climate, human activity, fisheries and resilience in coral reef systems (case study: the Galapagos Marine Reserve)
- contrast the main management systems in fisheries (spatial management, input controls, output controls, property rights) and briefly explain the opportunities and challenges they present

Oceans and Coastal Communities

The National Ocean and Atmospheric Administration of the United States puts it poetically enough: "The ocean is the lifeblood of Earth, driving weather, regulating temperature, and ultimately supporting all living organisms. Throughout history, the ocean has been a vital source of sustenance, transport, commerce, growth, and inspiration" (http://oceanservice.noaa.gov/facts/exploration.html). Oceans cover around 70% of the Earth's surface (Bollman et al., 2010) and contain 97% of the planet's water (NOAA, 2016), and despite the immense advances in oceanography that have been made in recent decades, more than 95% of the underwater world remains unexplored (NOAA, 2014). This is not surprising: the average depth of the ocean is about 12,100 feet (NOAA, 2015); and the deepest part of the ocean, named the "Challenger Deep" after the HMS *Challenger*, whose crew first sounded the depths of the trench in 1875, is approximately 36,200 feet from surface to floor: that is over 11lm deep! However, as we will see, some of the most important parts of the ocean are in fact not that deep at all: the coastal areas and human communities that interact with the ocean on a daily basis, forming an ecosystem with a prominent human dimension.

It is important to understand that the ocean is constantly moving. Ocean currents transport enormous amounts of heat around the world, making them one of the most important driving forces of climate (Bollman et al., 2010). At the global scale, around 400,000 cubic kilometres of water travel around the world, which corresponds to about one third of the total ocean's volume (Bollman et al., 2010). In a stunning example of system complexity, this massive circulation is driven by thermohaline currents (thermo = temperature; haline = salinity) and is known as the "**global conveyor belt**." In the process of convection, cold heavy salt water sinks to great depths, forcing the circulation of millions of cubic metres of water in the ocean (Bollman et al., 2010, p. 16). Although convection only occurs locally in a few polar regions, it propels thermohaline circulation around the globe, and is important for the global carbon cycle and world temperature stability.

To a lesser extent, wind patterns and eddies (flows between areas with marked temperature and density differences) also have an influence on ocean currents, creating waves which also influence ocean temperatures and nutrient levels in oceanic regions. Wind-generated waves can travel thousands of kilometers in the oceans before reaching land. They range in size from small ripples of less than a centimeter in height to over 30 m high (Affholder & Valiron, 2001). Waves affect all marine activities from shipping and fishing activities to the behavior of pelagic fish, shaping the coastline through erosion and wave-induced currents are the predominant process for transportation and deposition of near shore sediments (Affholder & Valiron, 2001).

More dramatically, tsunamis or seismic waves are caused by the large displacement of water, generally following an earthquake. Other events such as volcanic eruptions, underwater landslides, meteorite impacts and even glacier calvings can also cause tsunamis (Levermann, 2011). They can remodel the coast in the space of a few hours and are responsible for the death of hundreds of thousands of people. Finally, tides are a type of wave caused by the gravitational forces exerted by the moon and the sun and the rotation of the earth. (The sun is 27 million times more massive than the moon, but it is also almost 400 times further away; as a result, the moon exerts more than twice as much tidal force on the oceans and tidal bulge forms beneath and follows the moon.) Another tidal bulge forms on the opposite side of the planet where the moon's gravitational force is weakest due to the earth's rotation. Observations suggest that approximately half of the energy needed to power the ocean's global circulation pattern comes from tides (Egbert & Ray, 2000).

It is vital to understand that the ocean can store much more carbon than the atmosphere and the terrestrial biosphere (plants and animals). As the greatest carbon reservoir, it plays an important role in the global carbon cycle. However, it takes centuries for carbon to reach the deep ocean because of the slow mixing rate of water (Bollman et al., 2010). Therefore, the current ocean's CO2 uptake significantly lags behind its absorptive capacity through chemical processes. Anthropogenic CO2 emissions are occurring at a faster rate than they can be absorbed by oceans, leading to ocean acidification (see also Module 10).

Not only our primary carbon sinks, marine ecosystems are also a primary producer of plant biomass: "Around half of the worldwide primary productivity is achieved by microscopically small plants, the phytoplankton, which grow and divide in the ocean" (Bollman et al., 2010:114). Various threats to phytoplankton, from acidification to marine litter, threaten the entire food chain and therefore life on earth.

Coastal zones are also generally considered part of the ocean system: the ocean impacts the coast, and vice-versa, on a daily basis. This becomes especially clear when we look at land-based sources of marine pollution (including nutrient runoff from agriculture and microplastics from industry and sewage), and at the continual erosion of coastal land from waves. Indeed, many indigenous cultures do not make a clear distinction between land and sea but rather consider the land-sea interface as a continuum; as part of the same system.

It should come as no surprise that coastal areas are among the most densely populated regions of the world, as discussed in Module 6 on fluvial systems. The populations in coastal zones are growing faster than in any other region on Earth, with coastal cities expanding accordingly (Bollman et al., 2010). Experts estimate that over 40% of the world's population (i.e., more than 2.8 billion people) lives no more than 100 km from the sea, and this figure is likely to further rise in the future (Cluster of Excellence "The Future Ocean," 2015). Thirteen out of twenty (65%) of the mega-cities with populations over ten million are located in coastal zones (yet another reason why the prospects of sea level rises associated with climate change are so troubling). In many regions, this human density is further boosted by the millions of domestic tourists who seek out the coasts for various forms of recreation, from bathing to fishing.

Coastal zones are important for many reasons. Around 90% of the global fishery activity occurs in coastal waters. They are also the sites of important shipping routes and industrial facilities. Coastal areas contain important ecosystems and habitats that support biodiversity such as mangroves, coral reefs, seagrass meadows and salt marshes. Finally, they consolidate sediments flowing from rivers and influence many global processes in their role as a buffer between the land and sea. Mangroves (wetlands) are particularly important, containing trees species that can grow directly in seawater. Their roots are either permanently submerged or anchored in damp sediment. (Cluster of Excellence "The Future Ocean," 2015:62). These are important buffers, protecting inland from weather surges, and are important habitat for fauna and fish, providing livelihood for coastal communities. Equally important are coral reef systems, usually found near shorelines, some of the most biologically diverse areas in the world. Approximately one quarter of all marine fish species inhabit tropical coral reefs which makes them important areas for fisheries.

Oceans and coasts provide multiple ecosystem services that contribute to human well-being in multiple ways and that maintain conditions for life on earth. An overview is presented in the document "The Future Ocean" (Cluster of Excellence, 2015:44–45).

- **Provisioning services:** fish and seafood, transportation, renewable energy, goods for jewellery or souvenirs, non-renewable resources, pharmaceutical ingredients and other biochemical substances, genetic resources. Over 90% of fishing activity takes place within coastal waters.

- **Supporting services:** primary production, safeguarding biodiversity, nutrient cycle, maintenance of food web dynamics, maintenance of habitats, water cycle.
- **Regulating services:** coastal protection by dunes, coral reefs and mangrove forests; maintenance of air quality through algal production of oxygen or ocean uptake of carbon dioxide; maintenance of water purity by breaking down nutrients from wastewater and agriculture which enter the sea; climate regulation through the transportation of heat by ocean currents and heat exchange between water and atmosphere; maintenance of water purity by breaking down pollutants by means of dilution, chemical modification into harmless substances, or sinking and burial in the sediment.
- **Cultural services:** Contribution to science and to natural history education, religious and spiritual value of marine landscapes and places near and in the sea, inspiration, recreation and tourism, aesthetic value, cultural heritage

In short, oceans and coasts contribute to all dimensions of well-being. They contribute to material well-being through services that offer food, employment, protection and a healthy environment. Because so many people live on or otherwise depend directly upon coasts, the ocean is an important factor that shapes human relations, identity and culture, thereby contributing to relational and subjective well-being.

However, oceans and coasts should also be conceived as threatened, complex adaptive systems: despite their central importance for the biosphere, it could be argued humanity has neglected their ecological health to the point that ocean-related problems are wicked problems in the truest sense. They are continuously overexploited for resources, from fish to oil and natural gas reserves to sand, gravel, and rock; the extraction of genetic resources on the sea-floor and coral reefs for the development of new pharmaceuticals. Future ocean mining (ore mining at the sea floor) may damage deep sea habitats; and aquaculture results in the release of nutrients, pharmaceuticals and pathogens. Habitat destruction takes place on coasts for building projects, land reclamation or coastal; the clear-felling of mangrove forests for development or timber; the destruction of coral reefs as a result of coastal development, fishing, groundings of ferries and tourist boats, pollution of the seawater at the local level as a result of direct discharges of wastewater on the coast or from commercial vessels and cruise liners, and pollutants and sediments discharging into the marine environment from rivers, ocean warming and ocean acidification. Invasive species remain an ongoing threat to biodiversity, as does marine litter (especially plastic and microplastic) and nutrients, in particular phosphate and nitrogen, from agricultural sources and untreated wastewater (resulting in the eutrophication of coastal waters), and underwater noise pollution.

Ocean acidification is one of the most feared consequences of climate change as excess carbon dioxide upsets the chemical equilibrium of the ocean (Bollman et al., 2010). When CO2 dissolves in seawater, it forms carbonic acid, which dissociates to form an equilibrium with hydrogen ions, bicarbonate ions and carbonate. Continued uptake of CO2 by the oceans increases the concentration of hydrogen ions, thereby reducing pH, a phenomenon called ocean acidification (Caldeira & Wickett, 2003). One study notes that the "ultimate recovery of the oceans from ocean acidification … is achieved only through weathering on timescales of millions of years" (Bijma et al., 2009, p. 9). A 0.4 pH unit decrease (a two-fold increase in acidity) is expected in surface ocean waters by 2100 due to anthropogenic carbon emission.

These changes in pH are rapid (100 times faster than anything seen in the past hundreds of millennia – Dupont, et al, 2010). Unquestionably, ocean acidification will have widespread consequences for species and ecosystems (Caldeira & Wickett, 2003). Many organisms that live in the ocean use calcium carbonate ($CaCO_3$) which is dissolved in seawater, as building material for their skeletons and shells. $CaCO_3$ is therefore crucial for corals, molluscs, echinoderms and crustaceans. Under acidic conditions, carbonate ions are less available because they will combine with hydrogen ions (H+) to form bicarbonate ions (Doney et al., 2009). In extreme cases, a decline of calcium carbonate can lead to the dissolution of marine organisms' existing carbonate shells, skeletons and other structures (Seijo et al., 2016).

The *phytoplanktonic coccolithophores* are one of the most abundant marine primary producers found in the oceans. These species have a carbonate shell and most studies have reported a reduced rate of calcification (Hofmann et al., 2010). Besides their role as primary producer and the base of the food web, coccolithophores contribute to cloud formation through chemical reactions when they die (Malin et al., 1993). A reduction in clouds would reduce the reflectivity of the Earth and thereby increase the rate of global warming. Foraminifera are another abundant planktonic single-celled organism with a carbonate shell. They are not part of the phytoplankton, but still remain important as part of the marine food base. Ocean acidification will impact both their metabolism and their calcification rate (Longphuirt et al., 2010). Shelled pteropods are planktonic snails and an important component of polar and subpolar ecosystems which will also be affected (Longphuirt et al., 2010). While some groups of planktonic species show negative responses to ocean acidification, others have positive responses, and others still show no conclusive results (Riebesell & Tortell, 2011).

Other potential impacts of ocean acidification on marine species include changes in metabolic rates, reproduction, growth, and drops in immune response to other organisms such as parasites or bacteria (Longphuirt et al., 2010; Seijo et al., 2016). Acidic environments disrupt the sense of smell in fish (Bollman et al., 2010) and can interfere with the construction of calcium carbonate internal structures such as ear bones and balance organs (e.g. otoliths in fish and statoliths in squids) (Longphuirt et al., 2010). Finally, acidification can change the acoustics in water by changing its chemistry; this can impair the ability of marine mammals to detect calls and echolocation pulses (Longphuirt et al., 2010).

The overall effects of ocean acidification are difficult to predict. For example, increased CO2 is good for plants such as seagrass which are important feeding and spawning sites for a variety of species (Longphuirt et al., 2010). We do not know if local benefits of better seagrass will be outweighed by the wider disruption to the marine food web as a whole, and what that will mean for marine biodiversity. Given that different species react differently to ocean acidification, each change in one species is likely to affect ecosystem structures in complicated ways (Doney et al., 2009); and ocean acidification is occurring at the same time as a number of other stressors such as climate change, eutrophication, invasive species and fishing pressure (Doney et al., 2009). The interaction between these stressors are poorly understood and difficult to predict (Longphuirt et al., 2010): an example of system complexity if there ever was one!

Towards Ecosystem Approaches in the Wicked Problem of Overfishing

One area of economic activity that will certainly be affected by acidification is commercial fishing, already under severe stress. About 20% of humankind's nutritional needs are met from the sea, and the livelihoods of 600 to 820 million people worldwide depend directly or indirectly upon fisheries, which pull up to 80 million tonnes per year from oceans worldwide. Fisheries governance has been explicitly recognized as a wicked problem (Jentoft & Chuenpagdee, 2009, 2015). Common-pool resources such as fish stocks are a class of resources that are particularly problematic to manage. They share two characteristics which in combination cause serious problems (Acheson, 2006). First, it can be difficult to control access to the resource or to exclude people from using the resource (referred to as the "exclusion problem"). Second, the amount of the resource used by one person cannot be used by another, meaning that each user can subtract from the welfare of all other users (referred to as the "subtractability problem") (Berkes, 2006; Ostrom, 1990). Finally, the diversity, complexity, dynamics and scales in fisheries require constant monitoring of the ecosystem (Jentoft & Chuenpagdee, 2009).

Fisheries and coastal governance must deal with competing biological, economic and social goals that are closely linked (Jentoft & Chuenpagdee, 2009; Kooiman et al., 2005). When addressing one objective, governance will intentionally or unintentionally affect other domains. The wickedness of the governance problem is enhanced when actors' values don't align (Jentoft & Chuenpagdee, 2009). Moreover, people have different interests and distributional issues such as allocation are always an important and contested issue in fisheries. For example, the conflict between small-scale and large-scale fisheries involves issues of poverty, food security, habitats, communities and gender (Jentoft & Chuenpagdee, 2009).

Given the fact that actors have different goals, values and interests, it follows that they often have different perceptions about the problem and its potential solutions (Jentoft & Chuenpagdee, 2009). Management tools reflect a certain ideology and are not value-free (Jentoft & Chuenpagdee, 2009). Fisheries policies tend to have a strong element of path dependency and management measures may be nearly irreversible (Hersoug et al., 2000; Jentoft & Chuenpagdee, 2009, 2015). Politics will also determine which questions are raised. Therefore, the setting of goals, problem definition and proposed solutions are political and are usually challenged in fisheries (Jentoft & Chuenpagdee, 2009). Conflicts over policies are never fully resolved. Such a situation may create issues about legitimacy and lead to problems of compliance (Jentoft & Chuenpagdee, 2009).

Fisheries management and governance is therefore particularly difficult due to technical challenges with stock assessment, competing objectives (e.g. economic efficiency vs livelihood), social and cultural conflicts, and lack of alternative livelihoods. The dominant model in conventional fisheries science and management follows the metaphor of the "Tragedy of the Commons" (Hardin, 1968): fisheries evolve towards intense competition characterized by over-capitalization, followed by the inevitable over-harvesting of the species. The tragedy is therefore both environmental and economic (McCay & Acheson, 1987). Such failures are attributed to imperfect property rights and incentive structures. Hence, the solution resides either in the market (privatization) or in government control (public resources).

Management remains largely based on single-species despite repeated calls for ecosystem-based management in fisheries (Crowder et al., 2008; Jackson et al., 2001; Millenium Ecosystem Assessment, 2005; Pauly et al., 2002). Because decision-making is solely informed by fisheries science and performed by actors removed from the resource, it will tend to focus on the large scale (e.g. the whole stock) (Hilborn et al., 2005). Thus, it will ignore local-level variations in abundance of the resource and in habitat (e.g., bottom types, particular flora, depth, and water conditions) (St. Martin, 2001). Implementing regulations that ignore the environmental landscape can create damaging local ecological impacts but that seem insignificant at the level of the entire management area (Hilborn et al., 2005; St. Martin, 2001). However, focus at the stock level can also detect changes that are not apparent at the local scale. For example, aggregating fish species will exhibit hyper stable catch per unit effort (CPUE) while the stock is declining until it is very close to collapse (Rose & Kulka, 1999). Moreover, issues of trust between fishers and scientists in a context where fishers are viewed as “the fox in the henhouse” can make the sharing of this knowledge more difficult. Without access to local knowledge and observations, feedback loops between the status of the resource and decision-making are longer, which can substantially delay needed actions and have a negative impact on the sustainability of the resource (Berkes, 2002; Folke et al., 2005)

Conventional fisheries management has evolved in a similar fashion throughout the Western world. Fisheries essentially remained free, unregulated, and open-access up until the end of the 19th century when the exhaustibility of fishing resources became apparent (Scott, 2000). Attempts at reducing harvest pressure began by implementing input controls (i.e. measures controlling fishing methods) by means of targeted gear restrictions (e.g. vessel types and power, net mesh size, types of trawls, etc.), area closures, fishing seasons, and minimum landing sizes (Merrifield, 1999; Scott, 2000). These regulations were meant to encourage reproduction by increasing escapement of spawning and under-sized fish (Scott, 2000). When this proved inadequate, seasons became shorter and gear restrictions increased. However, it became clear in the 1960s that these regulations alone could not control ever-increasing capacity of fishing vessels. Fisheries management turned to limiting effort and restricting access with entry barriers, commercial fishing license limits, or license buyback programs (Merrifield, 1999; Scott, 2000). Restricting access did not change the incentive to “race for fish” and overcapitalisation in fisheries continued to increase, wasting economic resources (Shotton, 2000).

It is no secret that conventional fisheries management is struggling. Many fish stocks are declining or have already collapsed (Hilborn et al., 2003; Jackson et al., 2001; Zeller & Pauly, 2005). The main cause of fisheries depletion and collapse is overfishing. Other important factors include habitat destruction, pollution, climate change, and invasive species.

Although the magnitude of reductions in open-ocean pelagic predators is still debated (Hampton et al., 2005; Walters, 2003), evidence supports that these species have experienced significant declines with estimates ranging from 50-70% (Hampton et al., 2005) to up to 90% (Myers & Worm, 2003). Catastrophic stock collapse is probably the most notorious failure of conventional fisheries management. A few classic examples include the bluefin tuna, North Sea herring and mackerel, northern cod in Atlantic Canada, Norwegian spring-spawning herring and British Columbia's Fraser River sturgeon (Mackinson & Nottestad, 1998). Entire food webs have been significantly altered by overfishing (Christensen et al., 2003; Jackson et al., 2001; Walters et al., 2005). Commercial fisheries continuously shift their target towards lower trophic levels in response to declines in larger, slow-growing species relative to smaller, faster-growing species; a process now known as "fishing down marine food webs" (Pauly et al., 1998, 2000; Pauly & Palomares, 2005). It is argued that these shifts in exploitation signal changes in ecosystem structure (Pauly et al., 2001; Verity et al., 2002)

The effects of fishing can cascade both upward and downward through food webs, resulting in reductions in species diversity, total biomass, and the provision of ecosystem function and services (Micheli & Halpern, 2005; Myers et al., 2007; Walters et al., 2005). Cascading causes nonlinear and often surprising changes in ecosystems which can also lead to regime shifts by changing the overall species composition of communities (Daskalov, 2002; Myers et al., 2007) or even result in ecosystem collapse (Mangel & Levin, 2005; Worm et al., 2006). For example, the removal of herbivorous and predatory species has resulted in regime shifts affecting ecosystems from coral reefs to the open ocean (Folke et al., 2004). Species removal in previously complex food webs can even cause ecosystems to collapse, such as the Caribbean reefs now dominated by algal communities following depletion of various reef fishes (Bellwood et al., 2004).

Discards and by-catch have also been issues of concern in conventional fisheries management (Hilborn et al., 2003; Kelleher, 2005). Although there is evidence for a substantial decrease in discards in the 1990s, the most recent estimate for annual global discard is 7.3 million tonnes, representing a discard rate of 8% of the world's catch (Kelleher, 2005). Seabirds, sea turtles, marine mammals, and chondrichthyans (sharks, rays, and chimaeras) are particularly vulnerable to being caught as by-catch (Lewison et al., 2004; Lewison & Crowder, 2006). It is estimated that more than 650 000 marine mammals are taken in fisheries each year (Read et al., 2006), with some species' survival being directly threatened due to by-catch (D'agrosa et al., 2000; Jaramillo-Legorreta et al., 2007; Read et al., 2006). Sharks in the northwest Atlantic have declined by 50%–90% because of by-catch in the tuna and swordfish longline fisheries (Baum et al., 2003).

However, the strongest ecosystem impacts of commercial fisheries are from mobile bottom fishing gears. Bottom trawls, dredges, and traps reduce heterogeneity and structural complexity in both hard- and soft-bottom habitats, which result in habitat destruction, loss of refuge, and subsequent reductions in species survival (Thrush & Dayton, 2002; Watling & Norse, 1998). Severe declines of density and biomass of certain benthic species have been observed in response to trawling, as well as reductions in sea grass beds (Blaber et al., 2000).

From an ecosystem approach it is especially troubling that conventional fisheries management has often neglected the socio-economic dimensions of fisheries (Cury, 2005). Social impacts vary with specific management arrangements and implementation and are therefore difficult to generalize. Reduction in employment and concentration of harvest privileges in the hands of fewer fishers may lead not only to a reduction in the number of fishers, but also to a reduction in size or even elimination of some fishing communities. (Bess, 2005; Bradshaw et al., 2000; Gibbs, 2008; Maurstad, 2000; McCay, 2000; Stewart et al., 2006; Wingard, 2000). Limiting access to a fishery can not only disrupt individual fishing operations, but can affect entire communities and regions economically and socially reliant on commercial fishing (McCay, 2000). This disruption leads to loss of existing social capital which can be a critical force behind economic growth (Copes, 2000). Community structure is modified by the formation of socioeconomic classes of individuals that control access to the fisheries and classes of those that depend on those with access to the fisheries. This inevitably disturbs the social equilibrium, reallocating social prestige, power, and respect (Arnason, 2000; Bess, 2005; Helgason & Palsson, 1997; McCay, 2000; Wingard, 2000).

The failure to reverse, or even slow down, stock declines led to a shift in the focus of centralized fishery management from input to output control (Bradshaw et al., 2000; Hilborn & Walters, 1992; Scott, 2000). Input controls are still present in most fisheries but as a supplement to other measures, including caps on the number of fishing licenses, size limits on fish (e.g. minimum landing size), area closures, rotation of fishing grounds, temporal limits (e.g. fishing seasons), gear restrictions and effort controls (e.g. days at sea). Input controls are usually used in combination with offering the possibility of devising management arrangements tailored to the specific local conditions of the fishery. Although management systems are diverse, most Western managed fisheries operate under a system that builds upon Total Allowable Catch (TAC) for individual species accompanied by technical measures such as gear restrictions, minimum mesh sizes, closed areas and seasons (Hilborn & Walters, 1992; Rijnsdorp, 2007).

Fisheries serve as an important example of people trying to adapt to the challenge of a sustainable economy in relative harmony with an ecosystem. Lessons learned from small-scale fisheries that engage in self-governance include:

- Community self-organization is possible (in other words, the tragedy of the commons is not inevitable)
- Importance of local rules (formal and informal), norms and community cohesion
- Short feedback loop between environmental observations and action (adjusting behaviour and rules to changing conditions)
- Contributions of different types of knowledge and values to sustainability
- Local communities do not have the capacity to fully address external forces such as macroeconomic and policy processes beyond their control. Governance arrangements must fit the scale of the problem and often requires partnerships across scales to be effective (such as co-governance) (Berkes, 2006; Jentoft & Chuenpagdee, 2015).

Case Study

Governance of a large marine ecosystem: The Baltic Sea (Österblom et al., 2010)
Even a comparatively simple biological marine system with low species diversity is complex to manage, a consequence of ecological regime shifts, cross-scale ecological interactions and social–ecological dynamics.

The Baltic Sea consists of a number of sub-basins, defined as the Sound. The coastal ecosystems are typically structurally complex and locally variable in comparison to the open sea, and there are also large regional differences. The Baltic Sea ecosystems underwent ecological regime shifts in the late1980s in response to multiple stressors: hydro-climatic changes combined with overfishing and/or nutrient loading. The regime shift that occurred in the Central Baltic Sea led to a trophic cascade that significantly altered ecosystem structure, whereas no such trophic cascade was observed in the Sound. The ecosystem in the Central Baltic Sea has remained in the new regime, even though the external forcing variables (hydro-climatic variables, nutrients and fishing pressure) have returned to the state before the regime shift. This indicates that a new state in the food web has been stabilized by feedback loops (hysteresis mechanisms). The difference in regime shifts between the Central Baltic Sea and the Sound suggests that a single pressure (in this case overfishing of cod) has eroded ecosystem resilience, thereby making it more vulnerable to variations in climate.

The Baltic Sea is significantly shaped by human activities, some of which have to be managed in an international context, others that can be addressed at local and sub-basin levels. Environmental policies in the Baltic Sea have been developed on a sector-by-sector basis. However, the ecosystem approach has been accepted since 2003 as the framework for the Helsinki Commission (HELCOM) – the main forum for international environmental cooperation (all riparian states are members). Despite this political commitment, the organization has not been able to achieve their priority to reduce the negative effects of eutrophication. Implementation of agreed measures is hampered by the voluntary nature of HELCOM cooperation, and the lack of sanctioning mechanisms.

There has been a range of recent policy developments in the Baltic Sea which support a transition to an ecosystem approach. These include the implementation of the European habitat and bird directives, the European Common Fisheries Policy (CFP) reform in 2003, and the EU Marine Strategy Framework Directive (MSD). As opposed to HELCOM, EU legislation and policies have strong sanctioning mechanisms. Interesting innovations to address social–ecological dynamics at different spatial scales are also emerging. This diffusion of innovation was enabled by interactions between science, policy and practice from local to European levels. Top-down enabling legislation and bottom-up practices have both led to a diffusion of innovation affecting practices at other scales or in other sectors.

"Although recent political actions to reduce overfishing and eutrophication, as well as expected future initiatives for marine spatial planning are important, these actions are likely relatively inefficient without stakeholder consultation, engagement and participation across interest groups. Emphasis on multi-level governance structures that provide space for experimenting and spread of social innovations at local and regional scales can provide key elements for stimulating an adaptive capacity for dealing with this dynamic ecosystem and the services generated." (Österblom et al., 2010, p. 1297)

Discussion points

1. Discuss the ways in which oceans play a fundamental role in ecosystem services, and how the disruption of these processes could have an impact on the global biosphere.
2. How can fishers' knowledge contribute to fisheries management and governance?
3. How can we raise awareness about the problem of ocean acidification and how should we address it?
4. Is aquaculture a solution to the overfishing crisis?
5. Why do you think we typically ignore the wicked problems associated with oceans today?

Annotated Bibliography

Bollman, M., Bosch, T., Colijn, F., Ebinghaus, R., Froese, R., Güssow, K., et al. (2010). *World Ocean Review 2010: Living with the Oceans*. World Ocean Review: Living with the Oceans (Vols. 1-4, Vol. 1). Hamburg: Maribus, Future Ocean: Kiel Marine Sciences, International Ocean Institute, Mare. Retrieved from http://worldoceanreview.com/wp-content/downloads/wor1/WOR1_english.pdf. *This report provides a comprehensive, accessible and well-illustrated review of the complex state of the world's oceans and underline the urgent need for action. Important topics relevant to this module include the role of the ocean as a climate driver, the links between climate change and ocean chemistry, the uncertain future of the coasts, marine pollution and fisheries.*

Jentoft, S., & Chuenpagdee, R. (Eds.). (2015). *Interactive Governance for Small-Scale Fisheries*. MARE Publication Series (Vol. 13). Cham: Springer International Publishing. Retrieved from http://link.springer.com/10.1007/978-3-319-17034-3. *This book presents case studies covering small-scale fisheries in a great number of biophysical, social, economic, cultural, political, and governance settings. The case studies are grouped around seven themes focusing on governability challenges, aligning modes in governing system complexity, rights and justice concerns, securing space, cross-boundary governance, governance in transition, and meta-governance. The case studies cover small-scale fisheries governance through self-governance, pure and hybrid forms of traditional community-based and modern co-governance, hierarchical top-down governance modes, and many forms in-between.*

Jentoft, S., & Chuenpagdee, R. (2009). Fisheries and coastal governance as a wicked problem. Marine Policy, 33(4), 553–560. *In this paper, the wicked problem of fisheries and coastal governance is identified as a governability issue, recognizing that there are limitations to how rational and effective fisheries and coastal governance can possibly be. The paper offers a framework which can help locate the wicked problems within the fisheries and coastal governance system, as well as examine their governability.*

Longphuirt, S. N., Stengel, D., O'Dowd, C., & McGovern, E. (2010). Ocean Acidification: An Emerging Threat to our Marine Environment. Marine Foresight Series. Galway: Marine Institute. *This report reviews the threats of ocean acidification with a focus on policy development and the ecosystem approach.*

Österblom, H., Gårdmark, A., Bergström, L., Müller-Karulis, B., Folke, C., Lindegren, M., et al. (2010). Making the ecosystem approach operational—Can regime shifts in ecological- and governance systems facilitate the transition? *Marine Policy*, *34*(6), 1290–1299. *This article describes the long-term social–ecological changes in the Baltic Sea, illustrating how the process of making the ecosystem approach operational in a large marine ecosystem can be stimulated.*

Recommended websites

The Multimedia Discovery Mission Demos are a series of 14 interactive multimedia presentations and learning activities. Each topic contains two short videos: a lesson covering theory and an overview of the global impacts. For this module the following are recommended:

Ocean currents. Overview of thermohaline and surface currents
http://oceanexplorer.noaa.gov/edu/learning/player/lesson08.html

Ocean waves
http://oceanexplorer.noaa.gov/edu/learning/player/lesson09.html

Tides
http://oceanexplorer.noaa.gov/edu/learning/player/lesson10.html

Hurricanes
http://oceanexplorer.noaa.gov/edu/learning/player/lesson14.html

Interactive Map of ocean and wind currents (click on Ocean currents in the column on the right below interactives):
http://oceanservice.noaa.gov/education/pd/oceans_weather_climate/welcome.html

Create a hurricane. Students must choose the right conditions to create a hurricane in this activity.
http://oceanservice.noaa.gov/education/pd/oceans_weather_climate/media/create_hurricane.swf

Video on wastewater pollution
https://www.youtube.com/watch?feature=player_embedded&v=itCOY7VviRU

Preventing Our Oceans from Becoming Dumps
https://www.youtube.com/watch?feature=player_embedded&v=uCXEHrmEYpM

Interactive slide show on ocean acidification, including an interactive model.
http://web.stanford.edu/group/inquiry2insight/cgi-bin/vu-r1a/vu.php?view=acidocean

Video: Demystifying ocean acidification and biodiversity impacts
https://www.youtube.com/watch?v=GL7qJYKzcsk

BBC Science Documentary on ocean acidification with English subtitles https://www.youtube.com/watch?v=zXFK3dWfFsk

Video on restoring oyster reefs with references to ecosystem services
http://ww2.kqed.org/quest/2013/10/22/restoring-oyster-reefs/

Explaining Marine social-ecological systems. Stokholm Resilience Centre researcher Henrik Österblom explains the dynamics behind marine social-ecological systems and ecosystem approaches to fisheries management.
https://vimeo.com/19976251

Module 8: Urban Ecosystems

Expected Learning Outcomes: upon completion of this module, students will be able to

- understand the importance of cities as socio-natural spaces and their significance for ecosystem resilience;
- understand and discuss some basic theories that explain the social-ecological nature of cities;
- discuss the fallacies — and effects — of reductively connoting ecosystems with 'pristine natures' thus rendering invisible the crucial roles that cities play in ecosystem dynamics;
- recognize city spaces, places, and processes that play important ecological roles;
- help develop, and participate in, a network of fellow students who aim to increase the ecological resiliency of urban spaces they inhabit.

Urban Ecology

This module introduces students to cities as vibrant social-ecological systems where ecosystem dynamics intertwine with socio-political processes and resiliency is located at the intersection of human and non-human worlds. 'Nature', ecosystems, and conservation areas are commonly associated with non-urban areas imagined as pristine environments that have endured little change by humans and are thus in need of protection from human impact. They tend to be contrasted with social spaces, especially with urban areas. While some ecosystems have been subjected to far less human impact than others, the divide between 'natural' and 'social spaces' is problematic. The co-evolution of humans and nonhumans in presumably 'natural' spaces becomes invisible, and conservation measures often fail because they do not take these dynamics into account, ignoring the cultural ecological knowledge that cultures develop in this context. On the other hand, this reductionism tends to render invisible the ecological importance of social spaces, especially urban areas.

Urban ecology relies on an ecosystem approach that also considers high density dwellings, commercial buildings, roads, light, noise, and other anthropogenic elements as "integral components" of the urban ecological landscape. Biodiversity is a key consideration in urban ecology as are cross-scale interactions between human and non-human processes. Many urban ecologists focus their efforts on studying/managing socio-ecological systems while aiming to understand and achieve socio-ecological resilience. These issues matter greatly because at least 54% of the world's population now lives in cities and it is estimated that by 2017 the majority of citizens of the global south will have moved into city dwellings, adding to the disproportionately large ecological footprints of large cities. However, it was not until recently that socio-ecological dynamics became priority considerations in the planning and management of city growth and urban expansion.

Though often considered a recent phenomenon, urbanization is an integral part of the history of human evolution, and it has not occurred without a deep ecological footprint. Although the first cities appeared in Mesopotamia over 6000 years ago, the exponential growth of urban areas at current rates of urbanization is a relatively recent phenomenon that sprang out of the industrial revolution. The commons closure movement that began in England during the 19th century was key to these transformations. People who no longer had free access to forests, fields, and waterbodies to procure their livelihoods began to move to cities in search of new job opportunities availed by the industrial revolution. As the industrial revolution and associated capitalist economies expanded, similar transformations spread on a global scale. Another reason why people moved (and continue to move) to cities is that they offer an impressive array of services that promise new forms of social resiliency as alternatives to those that had characterized pre-industrial rural communities. The rapid development of cities and the many problems this caused soon revealed the need to develop planning strategies for cities to assure at least a minimal quality of life for their inhabitants.

As the number and area of existing megacities around the world continues to expand, concern about the stress that cities put on ecosystems is also mounting. For example, while cities occupy less than 1% of our planet's surface they far exceed non-urban areas in the consumption of water, wood, and energy with rates that vary from 60% to 80% (see Wu 2014). To feed the masses living in modern cities, nutrients are drained from the rural landscape without replacing them (and excessive nutrients are often used to produce the food, which then drain into water sources, causing other problems). Cities are also major contributors to greenhouse emissions, and urban pollution has reached crisis levels at various points in history.

According to recent World Health Organization estimates, more than "80% of people living in urban areas that monitor air pollution are exposed to air quality levels that exceed WHO limits. While all regions of the world are affected, populations in low-income cities are the most impacted. According to the latest urban air quality database, 98% of cities in low- and middle income countries with more than 100 000 inhabitants do not meet WHO air quality guidelines. However, in high-income countries, that percentage decreases to 56%." (http://www.who.int/mediacentre/news/releases/2016/air-pollution-rising/en/). These are increasingly recognized as wicked problems in their own right: solving them will involve sacrifices and changes in governance that many people or governments are not ready to make.

While the history of urban planning reveals a pattern of focusing on issues that include health, poverty, social-inequality, and economic problems, the growing recognition of urban ecology as a field of study and of political intervention has resulted in a paradigm shift whereby the issue of socio-ecological sustainability is seen as crucial to the mitigation of the aforementioned problems.4) Urban ecology in the age of environmental concern — links to biodiversity, global climate change, and social sustainability: Although recognition of significant environmental problems in cities spans centuries (e.g. sanitation in ancient Rome, smog problems in early industrial Manchester and London), the environmental crises of the 20th and 21st centuries have drawn unprecedented attention to the challenges of urban ecology. The big difference is that whereas in the past concerns with the state of the urban environment tended to focus punctually on isolated issues, as the 20th century unfolded it became increasingly evident that urban environmental issues were ubiquitous and widely encompassing — urban environment dynamics were thus recognized as wicked problems which caused significant effects to the wider socio-ecological systems of which cities are part.

The field of urban ecology has been particularly concerned with understanding the intersection of urban environmental dynamics with three encompassing wicked problems: a) environmental degradation, b) biodiversity loss, and c) climate change.

a) The very physical existence of cities causes considerable **environmental impact**. River courses are often altered to accommodate the needs of expanding urban areas and growing commerce-related traffic in water ways. New Orleans is a prime example of such a process which lead to the destruction of the Bayous surrounding the city. Bayous are amongst the most valuable ecosystems on our planet. They are constituted by tree dominated swamps that hold large amounts of water thus acting alternatively as sponges in the event of excessive rain and/or flooding, as water reservoirs in the event of drought, and as barriers to storms and surges coming in from the ocean. Not only were New Orleans' Bayous uniquely rich ecosystems that provided important habitat to a ride range of species they provided important resources for humans while keeping them safe from storms. The destruction of the Bayous that surrounded New Orleans is the main reason why 2005 Hurricane Katrina caused so much death and material damage. Other ways in which urban expansion is associated with environmental degradation include the levelling of slopes and hills which, in turn, affects many ecological dynamics including the movement of water, winds, and living organisms. Cities also cause considerable impact as sites for the arrival an expansion of invasive plant and animal species given the concentration of trade and commerce that characterizes them.

b) The construction and expansion of cities is associated with significant **biodiversity loss.** Ancient Romans and ancient Greeks were the first to notice that urban expansion was often achieved at the expense of destroying entire ecosystems (especially forests) to clear the way for building. In fact, leading thinkers in ancient Rome and ancient Greece are amongst the first to have noticed that the destruction of these ecosystems also caused important changes to the climate of these areas including reduced rainfall. Cities also affect biodiversity in areas surrounding them when, for example, they are located in the path of important migration corridors for birds, insects, mammals, and even plants and trees (e.g. as planting zones change with natural as well as human inducted climate change plants and trees 'move' southward and northward accordingly).

c) Though industrial agriculture is a major contributor to **climate change-related greenhouse gas emissions**, the impact of cities outweighs that of non-urban areas. First of all, some estimates suggest that cities contribute 80% of total greenhouse emission gases. Secondly, given the extent of cement and tar-based surfaces that characterize most city development, cities produce and absorb disproportionate amounts of heat. Urban areas lacking reflective surfaces and or green spaces are particularly problematic in this regard. Third, the very ways in which cities are designed and managed often exacerbate these problems. Urban sprawl and poorly developed public transportation infrastructure are two central examples. The need to conserve urban biodiversity is another, since it is important to people as it is directly related to health, well being, and social equity. Given that soon most people on our planet will live in cities, and that most cities put great strain our planet's ability to produce new resources and act as a sink for the waste we produce, it is increasingly important that we develop a better understanding of urban ecology and different options for governance and management. The current socio-ecological challenges of urbanization call for new models, and this entails the challenge of how to imagine greener, ecological cities.

Managing urban socio-ecology

Goal 11 of the Sustainable Development Goals adopted by the UN General Assembly comes with many specific targets reflecting the importance of urbanization today:

Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable

11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums
11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons
11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries
11.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage
11.5 By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management
11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities

a) Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning

b) By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels

c) Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials.

As a whole, the issues identified above turn the issue of urban ecology into a wicked problem. First, the current state of urban ecology is the result of historical processes that span over centuries and even millennia. Second, urban ecological problems are often the outcome of entangled economic, social, and ecological processes that affect one another in ways that aren't always easily predictable and/or easily discernible. Thirdly, this is compounded by the fact that economic, social, and ecological goals are often perceived in opposition to one another. In short, for this reason there are no simple solutions to the challenges that urban ecology poses. Instead, a wide array of creative solutions covering many aspects of urban ecology is required.

Many solutions are being pursued and there are no magic bullets that can fix all problems of urban ecology in all urban areas. In other words, solutions to the wicked problem of urban ecologies must necessarily be contingent on the social, political, economic, and ecological dynamics of each individual city. Nevertheless, on a general level the following strategies have proven to be crucial: a) remediation/reconversion; b) green design; c) building sustainability.

a) **Remediation and/or reconversion** are measures that aim to transform cities so as to diminish their negative ecological impacts. Remediation may take, for example, the form of cleaning rivers from chemical pollution either by developing more effective sanitation systems and/or by helping restore ecosystems such that they are better able to absorb pollutants. Reconversion takes place when ecological problematically urban areas are transformed to overcome those problems. For example, when old highly polluting industrial complexes are transformed into living greened communities, the benefits for urban biodiversity, human health, and economic renewal are multiplied.

b) **Green design** entails the development and implementation of techniques for building structures and infrastructures that have lesser or even no negative environmental impact. Buildings that maximize heat absorption in winter, and light reflection in summer are examples of structures that deploy green design techniques. The development of rail and light rail systems to substitute for current uses of individual transportation are examples of infrastructural green design. Painting roof tops with reflective structures and planting roof top gardens – on both residential and larger building, such as schools, libraries, and factories, are two additional examples of putting green design principles into action.

c) Another critically important range of solutions to urban ecology problems fall under the aegis of **building sustainability**. This entails re-thinking the use of urban spaces towards the provision of important ecological goods and services. For example, many cities are now building sustainability by developing large scale tree planting schemes in cities, the creation of allotments where urban citizens can plant their own produce, or changing city by-laws and regulations to allow for greater flexibility in the use of urban land towards sustainability goals. When approached as part of a greater program of urban renewal that reflects an ecosystem approach, building sustainability can be viewed as a serious “paradigm shift” in how we conceive of urbanization.

It is also vital to realize that open systems have serious impacts on other systems, a fact we stressed in Module One of this course. Cities have a tremendous impact on the ecosystems that surround them, draining resources, nutrients, and human labour from rural, forested, and coastal regions. It is thus vital that people work across sectors, an approach stressed by the UNEP, to understand and collaborate in the common effort to achieve sustainability. Everyone from policy analysts to urban designers to health specialists must be involved, but as importantly there must be sustained communication between urban and non-urban stakeholders in the process (see Module 3 on the human dimensions of ecosystem management for more on the participatory demands of social ecological systems). It will be pointless to develop “greener” cities if related projects do not address the urban bias that has characterized most national and many international development plans.

Case Studies

New York's Central Park

The case of New York's Central Park illustrates the use of remediation and/or reconversion to mitigate the negative ecological impacts that cities carry and also the complicated social dynamics that such processes often entail. Central Park was first built as a result of the recognition that urban dwellers lacked access to green spaces for respite from the stresses of urban noise and other forms of pollution. After decades of negotiation, planning and construction the park opened to the general public in 1859. The process was however, fraught with tension because the lands that now comprise the park had been purchased by freed African American slaves and Irish immigrants. They had come to form a community of farmers over a period of 50 years but which had not integrated into New York's dominant social landscape. We will see in this module that urban ecology is often embroiled with matters social inequality and access; in other words, that the creation of environmentally sustainable spaces cannot been as separate from social issues. Nevertheless, the Park's more recent history offers illustration of the ways in which the ecological remediation in cities can actually achieve joint environmental and social goals. In effect, the reconversion of the area that now comprises Central Park took place at the height of the 1930s economic depression that left millions of people out of jobs in the United States. The Park's renovation thus became an important and successful strategy to provide assistance to the city's most socio-economically precarious population.

For additional information in the history of New York's Central park see https://en.wikipedia.org/wiki/Central_Park; Ted Lecture A Senior Vice President and Director of City Park Development for The Trust for Public Land, Adrian Benepe is one of the nation's experts on the nexus of the public, private, and non-profit sectors in public space development and management. He oversaw a major expansion of the city's parks system, including restoring historic parks such as Central Park and Battery Park, adding 730 acres of new parkland including Hudson River Park, Brooklyn Bridge Park, and the High Line, and laying the groundwork for an additional 2,000 acres of parks. 16:38 video https://www.youtube.com/watch?v=nkDgxsyZsrY&nohtml5=False See also https://www.youtube.com/watch?v=DZPMkXTOz8Q

Communities in Nature: Botanic Gardens Conservation International

Communities in Nature was a 5 year project in the UK that was conceptualized and overseen by Botanic Gardens Conservation International. It attributed grants to community level organizations who successfully submitted project proposals for the joint pursuit of ecological and social goals within urban settings. Each of the participating projects engaged regular citizens to participate in urban horticulture while simultaneously implementing strategies to achieve social goals. A project by Royal Botanic Gardens Edinburgh taught children how to produce food crops which also provided important ecological services — e.g. to pollinators. It also provided horticultural training to troubled youth (e.g. with criminal records) who thus underwent social re-integration and in some cases move onto college level horticultural degrees. Another project, by Bristol Zoo Gardens engaged citizens to help grow a national collection of calendula while helping retirees at a nursing home fight depression, offering Alzheimer patients at another institution a chance to benefit from Horticultural therapy, and extending many educational opportunities to children around the city. In Birmingham the project consisted of having British women teach immigrant Muslim women how to develop urban gardens as a way to simultaneously integrated into British society and contribute to the creation of green spaces in the city. This is a model that could be replicated across the globe and we struggle to deal with the environmental and social challenges of cosmopolitan cities.

See the following report detailing BGCI's Communities in Nature project https://www.bgci.org/files/Worldwide/Education/communitiesIN/Gulbenkian%20BGCI%20lr.pdf. See the following videos for examples of these projects https://www.youtube.com/watch?v=PxrwPP4rTA8 https://vimeo.com/68681866

Discussion points

1. Are there signs in your neighbourhood that you live within an urban ecosystem? What component parts of that system can you see on a daily basis?
2. What processes would you ideally investigate if you were mandated to develop a better understanding of the urban ecosystem you live in?
3. What does the interaction between human and non-human systems mean to you, and how do you understand these interactions in the context of your city?
4. What are the reasons why historically cities have not prioritized social-ecological and human wellbeing? Is this the situation where you live?
5. How has the latter reality been changing, and in particular in the part of the world where you live?

Annotated Bibliography

Cities Alliance 2007. Liveable Cities: The Benefits of Urban Environmental Planning - A Cities Alliance Study on Good Practices and Useful Tools. Washington DC: Washington, D.C. 20433, U.S.A. http://www.unep.org/urban_environment/PDFs/LiveableCities.pdf *Sanctioned by UNEP this report provides a widely encompassing review of the importance of procuring urban sustainability while also offering practical tools on how to achieve urban sustainability goals. It also includes a series of case studies from different countries around the world to illustrate best practices in the management of urban ecology.*

Dale, Ann, William Dushenko and Pamela Robinson 2012. *Urban Sustainability: Reconnecting Space and Place.* Toronto: University of Toronto Press, 2012. *A collection of essays that examine how rural and urban landscapes can be better integrated to improve the sustainability and resilience of both.*

Langner and Endlicher eds. 2014 Shrinking Cities: Effects on Urban Ecology and Challenges for Urban Development. Second edition. Frankfurt am Main, Berlin, Bern, Bruxelles, New York, Oxford, Wien Peter Land International Academic Publishers. *Offers an overview of the themes*

covered in this module including an accessible definition of urban ecology, the history of urban ecology research, a good diagram that illustrates urban social-ecological systems complexity, and links to other topics such as biodiversity and economics. http://www.peterlang.com/download/extract/40473/extract_56610.pdf

Robert Mugerauer, "Toward a Theory of Integrated Urban Ecology: Complementing Pickett et al." *Offers a scholarly overview of Urban Ecology in relation to its philosophical and epistemological dimensions, cross disciplinary intersections, micro-macro dynamics, and systems complexity*. www.ecologyandsociety.org/vol15/iss4/art31/ES-2010-3667.pdf

Jari Niemelä, "Is there a need for a theory of urban ecology?" *Provides a good discussion of the applicability of ecosystems theory in general to urban ecosystems including human dynamics*. https://helda.helsinki.fi/bitstream/handle/1975/213/1999-is_there_a_need_for_a_theory.pdf?sequence=1

Wu, Jianguo 2014 "Urban ecology and sustainability: The state-of-the-science and future directions." *Landscape and Urban Planning* 125:209–221. Provides an overview of Urban Ecology as a field of scientific inquiry with an account of the 90 year history of this discipline, a discussion of the transformations the field has undergone during this time, key theoretical orientations and debates, and the challenges of tackling the dynamics of human nonhuman relations within urban spaces.

Recommended websites

http://www.unep.org/resourceefficiency/Policy/ResourceEfficientCities/FocusAreas/UrbanEnvironmentalPlanning/tabid/101663/Default.aspx

http://www.unep.org/resourceefficiency/Portals/24147/scp/REC/UNEP%20framework%20report%2048pp.pdf

https://en.wikipedia.org/wiki/Urban_ecology

http://www.society-urban-ecology.org

http://www.ecologyandsociety.org/vol11/iss1/art34/

https://feedingninebillion.com/sites/feedingninebillion.com/files/images/users/emaillou/Environments%20proofs.pdf

http://www.virtualmuseum.ca/edu/ViewLoitLo.do;jsessionid=3B0D725CF5B4AF3BB1BD37CB1E038BC2?method=preview&lang=EN&id=25646

Dickson Despommier is the Emeritus Professor of Public Health and Microbiology at Columbia University, on the vertical farming concept: 16:12 video https://www.youtube.com/watch?v=XO2mVBTeBtE&nohtml5=False

Post-Sustainability: New Directions in Ecological Urban Design; Sustainability is a good thing. But is it good enough? Shortened video from the 1 hour original https://www.youtube.com/watch?v=K4rB5VaBhz8&nohtml5=False

Vikas Mehta Cincinatti USA Urban Ecology Ted Lecture https://www.youtube.com/watch?v=DZPMkXTOz8Q 16:37 video

Water systems in urban biodiversity https://www.youtube.com/watch?v=6oyaFsVjGgI

Backyard Biodiversity project: creating habitat gardens in the City of Boroondara Australia https://www.youtube.com/watch?v=RY85oaBjoOs 6:52 video

URBES Barcelona SPAIN - Embracing the Vision of a Greener Future 7:27 video

India's Urban Transformation / CityLab 2015 Debate 26:37 video https://www.youtube.com/watch?v=wb0k720koX4

Japanese Smart Cities 12:46 video https://www.youtube.com/watch?v=gooul56oqwU

URBES Berlin Germany 9:07 viode https://www.youtube.com/watch?v=Yq1QtmmZTbs

Is Curitiba the world's greenest city? Brazil 10:10 minute video https://www.youtube.com/watch?v=tLjhSon0Ltw

Designing Affordable and Sustainable Urban Areas 26:30 video https://www.youtube.com/watch?v=Yxl-42U5_Io

Urban Botanic Gardens and Gardening Case Studies:

The re-invention of Botanic Gardens as conservation agents with important social roles 2:29 Video https://www.youtube.com/watch?v=c_592TG6eQI

PBS A Garden in Cairo Egypt 25:26 Video https://www.youtube.com/watch?v=WXgicBfh28g

Royal Botanic Gardens Edinburgh 6:10 Minute Video https://www.youtube.com/watch?v=PxrwPP4rTA8

Edible paradise on only 30 square metres: Marie Manning's Super-productive home garden 6:16 video https://www.youtube.com/watch?v=z2jE1TPlB2A

Module 9: Global Public Health and the Ecosystem Approach

Expected Learning Outcomes: upon completion of this module, students will be able to:

- discuss relevant health issues and appreciate health-benefitting ecosystem services
- understand the connections between humans, animal and environmental health, as well as their relation to anthropogenic, ecological and demographic drivers of disease
- discuss current and projected pressures on ecosystems and their implications for health
- distinguish between micro and macro-scale causes of disease
- identify integrated approaches (i.e. One Health or Planetary Health) that take an ecosystems view to strengthen understanding of disease dynamics
- analyze opportunities for synergies to promote health, the environment and sustainable development in land use, agriculture, urbanization, climate action and other planning and policy processes

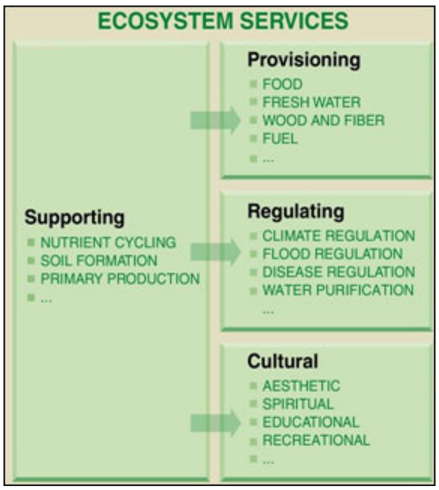
Public Health and the Ecosystem Approach

The World Health Organization (WHO) defines **health** as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO 1948). Public health refers to health at a population level (rather than individual level). The term is used in the context of human populations (although the health of other species is certainly important; but these are typically referred to as animal health, plant health, etc.).

Health status affects our length and quality of life, as well as our productivity. The United Nations recognizes the right to health by all people, but there are many factors that can promote or compromise health. Contributing factors are distinguished by individual, socioeconomic and environmental **determinants of health**. Individual determinants include our behaviors and characteristics (e.g. genetics), socioeconomic determinants include factors such as income and financial wealth, access to education, access to health services, and social networks and culture, and environmental determinants include factors such as weather, access to drinking water, and housing condition. Environmental determinants of health often intersect with socio-economic factors, including through pathways that may increase or decrease vulnerability to harmful exposures (for example, economic status may affect where people live and their housing condition, which can affect exposure to pollution).

The WHO estimates that 23% (12.6 million) of global deaths in 2012 were associated with environmental exposures and factors (WHO, 2016). Examples of direct health links to the environment include how air quality affects the prevalence of respiratory conditions (see the previous module on urban ecosystems), access to safe drinking water provided by our natural systems as well as sanitation infrastructure, and toxicity risks from acute and ongoing chemical exposures.

Our ecosystems contribute positively to our health in many ways. As part of the Millennium Ecosystem Assessment, the World Health Organization outlined the types of health-benefitting services that ecosystems provide (WHO 2005). These include *Provisioning services* such as food, water and medicines, *Regulating services* such as water purification, climate regulation, and flood protection*, Cultural services* such as recreational and spiritual services, and *Supporting services* such as soil formation, pollination, and nutrient cycling. The loss of certain ecosystem services can compromise the health of humans and other species. As noted in chapter 4, the loss of natural pollination services can reduce yield of agricultural products that we depend on for nutrition.



Source: Millennium Ecosystem Assessment via *http://www.who.int/globalchange/ecosystems/en/*

Consistent with the WHO's definition of health, health and wellbeing are in many ways linked; and ecosystems provide important material, relative and subjective contributions to wellbeing that can benefit health. *Material* contributions such as traditional medicines for treatments as well as compounds that inform synthetic biology in modern medicine, the nutrients needed for proper functioning, and spaces to recreate for physical activity. *Relational* dimensions of well-being such as social cohesion and livelihoods contribute to the social determinants of health. Direct or existential access to medical care and natural areas can support mental and emotional health in addition to physical health status as a *subjective* dimension.

Global health has achieved important advances in past decades as a result of important public health technology and capacity developments, such as vaccine production, sanitation systems, and therapeutics including antimicrobials, which have helped to increase life span, reduce childhood mortality rates, and reduce the incidence and burden of infectious diseases, especially in developed countries. Yet the current and anticipated pressures related to environmental change threaten the health of populations in addition to their broader ecosystems (Whitmee et al. 2015). In Module 2 we learned how ecosystem services are vital to human health; we cannot survive or prosper without them.

Think back to the threats to biodiversity reviewed in Module 4. Many of the factors contributing to biodiversity loss also overlap with **drivers of disease** (WHO-CBD 2015). For example, habitat change often corresponds to changes in land use (for example, deforestation, natural resource extraction associated with activities such as timber logging, mining, conversion to monocultures, and oil extraction), which can change ecological community composition and function, and often involve practices that put humans in new contact with animals as well as the introduction of new corridors that can move and connect both people and pathogens.

Crop and livestock diversity contributing to dietary intake is decreasing; for example, three crops now provide 40% of calories globally, with similar trends for livestock breeds (WHO-CBD 2015). While these may in some cases yield production benefits, low genetic diversity poses threats for climate, disease, and other stressor adaptation potential. In addition, dietary patterns are transitioning to increased livestock consumption at a rate that both demands high resource (land, feed and water) inputs and is leading to higher non-communicable disease burdens (WHO-CBD 2015). Inequitable access and distribution of food and nutrients leads to overconsumption in some populations (which has risen substantially over recent decades, contributing in part to energy imbalance with reduced physical activity, leading to obesity and related conditions including Type II diabetes and cardiovascular diseases) and under-nutrition and lack of food security in others (TEEBAg 2016). Micronutrient deficiencies- which are fully preventable- threaten the health attainment of the 2 billion people they affect; for example, 250 million pre-school children still suffer from vitamin A deficiencies, which can lead to childhood blindness and susceptibility to mortality from infections (TEEBAg 2016).

Dietary risk factors have been estimated to contribute to one-tenth of the global burden of disease (IRP 2016). Furthermore, the overexploitation and degradation of natural resources is in many cases negatively affecting supply of a range of ecosystems systems for nutrition – such as the ongoing provision of pollination to support agriculture, and supply of ocean fish for protein. Depleted soils reduce nutrient availability – and thus lower concentrations of nutrients in our food. Poor nutrient efficiency and high resource inputs for agricultural management (e.g. pesticides, added nitrogen and phosphorus, intensive water usage, and fossil fuel inputs) further contribute to pressures on the environment- such as chemical exposures, toxic algal blooms, water diversion leading to drought, and carbon emissions leading to climate change- that may have other negative outcomes ('externalities') on human and wider ecosystem health (IRP 2016).

Environmental pollution directly threatens health through exposure to harmful substances, including through the food chain (as seen with bioaccumulation of methylmercury in marine fishes and risk to human health through seafood consumption), air, and water. Certain populations (e.g. some occupations) may have heightened exposure risk- as seen with pesticide use in agriculture, including exposure to endocrine-disrupting chemicals, and with heavy metal poisoning in disassemblers/recyclers of e-waste (UNEP 2016). Pollution may also support the introduction and persistence of pathogenic microbes in water sources (as seen with cholera).

Climate change, discussed in more detail in the next chapter, presents health threats from extreme weather, including heat stress, water scarcity vulnerability, and potential changes in ecological ranges for disease vectors; health also may be threatened by the processes that contribute to or are often associated with climate change (e.g. deforestation and air pollution). Air pollution accounts for 7 million premature deaths each year (plus a range of respiratory and other conditions), a large share from exposure to indoor air pollution associated with cookstove burning of solid fuels. Forest, peat and grassland fires (often associated with intentional deforestation for palm oil and logging activities) affects air quality and causes an estimated

260,000 deaths annually (UNEP 2016; WHO-CBD 2015); these may also lead to displacement of populations as human settlements expand toward the boundary of forest areas and ecosystem resilience to disturbance diminishes from forest die-back.

Environmental factors account for a significant portion of persistent global health challenges – both infectious (e.g. malaria, cholera) and non-communicable (e.g. asthma, cardiovascular disease) diseases. For example, over 40% of disease burden (disability-adjusted life years) is attributed to environmental causes of malaria, including housing, waste, water and land management conditions that provide suitable breeding habitat for the mosquito vector, as well as exposure opportunities (WHO 2016). While the global malaria incidence decreased substantially through the concerted action under the Millennium Development Goals, malaria remains a leading cause of death in children under five, and some regions have seen new malaria risks associated with construction of dams or irrigation systems as well as habitat conversion that enables the presence of still water in previously-forested areas (WHO-CBD 2015). While risks vary by region and particular conditions, changing ecosystems and climates have also been raised as concerns for other mosquito-borne diseases such as dengue fever (as well as the potential establishment of Zika virus in new regions if brought in through infected travelers or invasive vectors).

Changing anthropogenic practices that enable or increase contact and connection opportunities with domestic animals and the environment can facilitate the transmission and spread of **zoonotic diseases**, which refers to diseases in humans originating from animals. Zoonoses represent approximately two-thirds of known human infectious pathogens, leading to over one billion human cases and a million deaths per year (Human Immunodeficiency Syndrome (HIV), Severe Acute Respiratory Syndrome (SARS), highly pathogenic avian influenza and rabies are other examples of the more than one thousand known zoonoses)(Karesh et al. 2012). For each of these, some spillover event happened that enabled transmission to humans, and in some cases, subsequent human-human transmission. While the burden of disease attributable to infections has declined over recent decades in large part from greater safe water access, improved sanitation systems, and the application of antimicrobials, the rate of *emerging* (newly-detected in a species or a region) infectious diseases appears to be on the rise, with the majority of recently-emerging (e.g. since 1940) zoonotic diseases originating from wildlife.

Disease is in many cases a result of many underlying drivers. For example, the emergence of Nipah virus (a zoonotic disease) in Malaysia in 1999 occurred when commercially raised pigs consumed fruit that had been contaminated by infected bats roosting in a tree next to the pig housing. Infection spread among the pigs, then to the farm workers and their contacts, ultimately resulting in over 260 known human cases, with spread to Singapore through imported pigs. The outbreak was facilitated by agricultural expansion (involving land use change and intensified commercial swine production) and a change in contact opportunities between bats, domestic pigs and humans (CBD-WHO 2015; Luby et al. 2009). Although antimicrobials have been a critical advance in our ability to fight infections, injudicious use can lead to the selection for resistant strains that may undermine our future ability to fight infections.

The development of antimicrobial resistance in human clinical use is widely appreciated as a major public health challenge, but food production (primarily agriculture and aquaculture) represents another potential source, in some cases indiscriminately used for prophylactic use and growth promotion. Intensive production conditions such as high stocking rates of animals, low genetic diversity, and stressful conditions may enable transmission. In addition to the risk of direct potential transfer of resistant strains to animal handlers, unmetabolized antimicrobials may be excreted in animal waste, and may be dispersed into the environment (CBD-WHO 2015; Karesh et al. 2012). While there is still much to be understood about natural versus medical and agriculturally-acquired routes of resistance development and potential for reversal of resistance, the recent detection of colistin-resistant strains, a systems approach, where we connect the dots between interacting components, is critical for evaluating the sources of, and possible solutions to, health threats.

Health is influenced by many possible contributing and diminishing factors occurring at different scales. As an individual human being, our body itself is a complex adaptive system, with many interdependencies, and it responds to constant flux. Think of our respiratory system, which is responsible for oxygen and carbon dioxide exchange – a process requiring air, lungs, airways, the heart, blood vessels, and many more parts for successful completion. When certain thresholds are exceeded, our body's relative homeostasis is disrupted and illness and even mortality can occur. Our individual internal body mechanisms (versus external ecological dynamics and societal infrastructure and practices) mean that health is shaped at many scales. The different scales provide constant potential for panarchy- thus, they must interact together to avoid catastrophe (harm to health).

Like the human body, a disease agent, such as a microbe or chemical (contaminants), also has its own set of characteristics. A microbe may or may not be pathogenic to a given species (in fact, most of the microbial diversity on the planet is not known to be pathogenic to humans, and many microbes, such as so-called **commensal bacteria** that exist in our gut microbiome, skin, and elsewhere, are essential for good health). A pathogen has its basic features—it may be a bacteria, virus, prion, or another type, and may have evolutionary features that promote its pathogenesis, persistence, and virulence. An individual host that comes into contact with a potential pathogen may or may not be susceptible due to factors including genetic makeup (e.g. a species without receptors for a pathogen to bind to) and baseline immunity from prior exposure or vaccination.

In addition to the individual and a disease agent, the environment provides many other natural and anthropogenic interactive determinants, such as sanitation systems that may or may not be in place, potential for the routes of transmission and spread, climate and weather that affect suitability of conditions for a contaminant or its vector, resource availability to strengthen immune status, dispersion of contaminants, exposure reducers or enablers (access to shelter, sanitation systems), healthcare services, and others. An individual may be able to control some exposures relevant to health, such as diet choices, physical activity levels, and behavioural risk avoidance, but some factors may remain out of our direct control (e.g. air quality, chemicals in a waterway from industrial sources). Contrasted with micro-level factors at a pathogen level, the macro-scale drivers of disease are important contributors to the health of populations (e.g. wide use of pesticides in food systems, climate change, trade and travel) may factor into health status; these cross-scale interactions are typical of **panarchy.** For example, the widespread use of antimicrobials for growth promotion in animal agriculture with high stocking density – considered a factor of changes in food production (macro-level)- may facilitate increased speed of genetic evolution of antimicrobial-resistant pathogens that can spread through the herd (micro-level).

International agreements can help promote protection from potential harms to health. Conventions such as the Stockholm Convention on the international trade of persistent organic pollutants (POPs), which recognizes toxicity threats from this class of industrial chemical used for applications including pest control and crop production, and concerns over its non-point source spread through water and wind, can help manage risk at a global level through standard setting and establishment of best practices. However, for the implementation of such conventions, national and local policy-making and enforcement is required to ensure that compliance consistently occurs and that risk monitoring and mitigation measures are available. This is not always so straightforward – for example, dichlorodiphenyltrichloroethane (DDT), an important mosquito control agent for reducing the risk of malaria infection in certain parts of the world, is a persistent organic pollutant linked to large-scale declines in birds of prey. The use of pyrethroid insecticides has rapidly increased over the last decade (now constituting the most widely applied spray insecticide); for example, permethrin is applied for malaria control, though in some cases cross-resistance to both permethrin and DDT has occurred (UNEP 2015). In high doses, it can affect the human nervous system and brain, with severe exposures potentially causing convulsions and loss of consciousness (ATSDR 2003).

Climate change is covered in detail in the next Chapter, but we should stress here the multiple impacts on human health that are anticipated. Harvested food resources that thrive under specific climatic conditions (including certain crops, orchard fruits, foraged plant species, marine fish and shellfish species) may have their distributions, abundance, and quality affected by shifting climatic conditions. Closely tied to issues of food security, this will have far-reaching and variable impacts on income and wealth or on livelihood (e.g. commercial fishing sector, subsistence harvesting; Schmidhuber & Tubiello, 2007) and on human health (new research shows that CO_2 concentrations are making food crops less nutritious; Myers et al., 2014). Human health will also be affected by changing disease exposure and vulnerability (Githeko et al., 2000; Kovats et al., 2001) and increasingly severe and common heat waves (Field et al., 2014). Between 1995-2004 an estimated 605,000 people were killed by weather-related events- and over 4 billion affected.

With increasing climate change, human security and livelihoods will be threatened by increasingly severe weather events, and environmental refugees will become more numerous (Reuveny, 2007; Warner et al., 2010; Stoett 2012), while many regions will be subject to drought conditions due to global climate change (Field et al., 2014). These collective impacts impose financial losses estimated in the hundreds of billions of dollars ($US) annually (UNEP 2016; United Nations Office for Disaster Risk Reduction 2015). A systems approach will demand that we consider how these looming threats to human health are interconnected and exacerbate their collective impact.

Responses: One Health and Planetary Health

The need to go beyond protection of only human health to wider ecological or ecosystem health is increasingly appreciated. Researchers have proposed defining healthy ecosystems as “one that is sustainable – that is, it has the ability to maintain its structure (organization) and function (vigor) over time in the face of external stress (resilience)” (Costanza and Mageau 1999). While there remains no standard assessment criteria to monitor the relative health of different ecosystems and tracking anthropogenic stressors, the IUCN Red List of Ecosystems, which assesses ecosystems for their threat of collapse and considers factors including degree of degradation, provides a possible approach (Keith et al. 2013).

Despite the ecological connections to current and evolving human health challenges, health is largely viewed in isolation from the health of animals and the environment. Approaching health problems through a comprehensive perspective that considers environmental determinants and drivers of disease can enable informed and proactive understanding and action to address major challenges facing our health and the health of our planet. One Health, EcoHealth and Planetary Health have been proposed as concepts to encourage a more integrated understanding of the connections between humans and our environment.

A **One Health** concept considers the integral links among human, animal and environmental health. The term was introduced in in the context of Great Ape deaths from Ebola virus. The Manhattan Principles were developed to provide guidance for a holistic approach to disease prevention and ecosystem integrity to support One Health implementation (please see Box 11.1) (Karesh and Cook 2005). EcoHealth (i.e. ecosystem or ecological health) shares close similarities with One Health, although the socio-economic, wellbeing and sustainability dimensions are typically more directly included in its definitions.

Examples of where One Health and EcoHealth can help include improving understanding of zoonotic and vector-borne diseases and their ecological and behavioral risk factors, identifying threats (and solutions) for food and water safety/production/security, assessing the health implications of land use decisions, developing risk analyses and mitigation strategies, and much more (OIE 2014). The USAID Emerging Pandemic Threats PREDICT project has supported the operationalizing of One Health approaches in over 30 countries, conducting screening for viral diversity in humans, domestic animals and wildlife to assess circulation of pathogens and identify the anthropogenic risks that enable pathogens to spill-over from one species to another (PREDICT Consortium 2014). Partners from ministries of public health, veterinary services/agriculture and environment/forests are involved in results interpretation, with a goal of coordinated understanding and response. However, such practices are not routine globally, with data sharing systems and coordination typically limited across ministries.

Box 10.1 The Manhattan Principles (Cook, Karesh and Osofsky 2004)

These “Manhattan Principles” urge world leaders, civil society, the global health community, and institutions of science to holistically approach the prevention of epidemic/epizootic disease and the maintenance of ecosystem integrity by:

1. Recognizing the link between human, domestic animal, and wildlife health, and the threat disease poses to people, their food supplies and economies, and the biodiversity essential to maintaining the healthy environments and functioning ecosystems we all require.

2. Recognizing that decisions regarding land and water use have real implications for health. Alterations in the resilience of ecosystems and shifts in patterns of disease emergence and spread manifest themselves when we fail to recognize this relationship.
3. Including wildlife health science as an essential component of global disease prevention, surveillance, monitoring, control, and mitigation.
4. Recognizing that human health programs can greatly contribute to conservation efforts.
5. Devising adaptive, holistic, and forward-looking approaches to the prevention, surveillance, monitoring, control, and mitigation of emerging and resurging diseases that fully account for the complex interconnections among species.
6. Seeking opportunities to fully integrate biodiversity conservation perspectives and human needs (including those related to domestic animal health) when developing solutions to infectious disease threats.
7. Reducing demand for and better regulating the international live wildlife and bushmeat trade, not only to protect wildlife populations but to lessen the risks of disease movement, cross- species transmission, and the development of novel pathogen-host relationships. The costs of this worldwide trade in terms of impacts on public health, agriculture, and conservation are enormous, and the global community must address this trade as the real threat it is to global socioeconomic security.
8. Restricting the mass culling of free-ranging wildlife species for disease control to situations where there is a multidisciplinary, international scientific consensus that a wildlife population poses an urgent, significant threat to human health, food security, or wildlife health more broadly.
9. Increasing investment in the global human and animal health infrastructure commensurate with the serious nature of emerging and resurging disease threats to people, domestic animals and wildlife. Enhanced capacity for global human and animal health surveillance and for clear, timely information-sharing (that takes language barriers into account) can only help improve coordination of responses among governmental and nongovernmental agencies, public and animal health institutions, vaccine / pharmaceutical manufacturers, and other stakeholders.
10. Forming collaborative relationships among governments, local people, and the private and public (i.e. non-profit) sectors to meet the challenges of global health and biodiversity conservation.
11. Providing adequate resources and support for global wildlife health surveillance networks that exchange disease information with the public health and agricultural animal health communities as part of early warning systems for the emergence and resurgence of disease threats.
12. Investing in educating and raising awareness among the world's people and in influencing the policy process to increase recognition that we must better understand the relationships between health and ecosystem integrity to succeed in improving prospects for a healthier planet.

Planetary Health is another term that acknowledges the role of the environment on human health and the pressures faced in the so-called anthropocene. Launched in a manifesto in *The Lancet* and the topic of a 2015 *Lancet* Commission report, it is defined as "the achievement of the highest attainable standard of health, wellbeing, and equity worldwide through judicious attention to the human systems—political, economic, and social—that shape the future of humanity and the Earth's natural systems that define the safe environmental limits within which humanity can flourish. Put simply, planetary health is the health of human civilisation and the state of the natural systems on which it depends." Planetary Health emphasizes health in relation to dependencies on natural systems and their degradation, including the thresholds for the biophysical planetary boundaries (Whitmee et al. 2015). Planetary Health pressures from the report include the status of fertilizer usage, water shortage, ocean acidification, tropical forest loss, carbon dioxide emissions, and others– and the resulting implications for human health. Unsustainable fisheries and loss of pollinators are among the examples noted as global effects of environmental change that reduce ecosystem services.

All three terms call for strengthening environmental health capacity and trans-disciplinary research and cross-sectoral action, and are recognized to have value for promoting biodiversity and health synergies (WHO-CBD 2015). An improved understanding of the mechanism that lead to disease can help us move from reacting to new health issues to preventing disease threats. For example, we can consider how changes in land use may affect health. Anticipating these changes during land use planning (for example, in policy processes such as REDD+, discussed in Module 5) could allow us to more fully weigh potential costs and benefits and optimize economic development, ecosystems and health.

The scope of health and environment becomes very broad when we consider the many external pressures/forces on ecosystems. Thus, anything we can do to reinforce the central theme that addressing future challenges requires broader engagement to anticipate risks and find preventive solutions can encourage action and a strong systems perspective. To do that we have to work together with the health and environment sector (in this particular module), but also many other sectors, including development, land use planning, oceans and coastal management, watershed and wastewater management, urban design, forest management, and many others that have been mentioned in this MOOC. There will always be trade-offs, but by identifying risks upfront we can better prevent them, rather than just respond to them (too often ineffectively) once they occur.

Case Studies

Early detection and prevention of Ebola virus outbreaks

The devastating impact of the West Africa Ebola epidemic beginning in late 2013 on human health (and ultimately leading to over 28,000 reported cases and 11,000 deaths) and on societies is well known. Perhaps less appreciated are the ecological links to Ebola, and the lessons they may offer for solutions to prevent future outbreaks in both people and animals. Outbreaks of the Ebola virus have occurred sporadically since the first detection in 1976. Ebola is recognized as a **zoonotic disease,** with a select group of bat species suspected as the natural reservoir (there are over 1,200 species of bats globally- many which are known to make key contributions for human health, such as in pest control and pollination for agricultural yield),.

Humans are not the only species impacted by Ebola virus. The virus has also caused declines of Great Ape populations in Central Africa over the past twenty-five years, including in some species that are already highly threatened by hunting, poaching (illegal harvest) and habitat loss. While some populations of some wild animals affected by Ebola (e.g. duiker antelopes) may rebound rapidly, the slow reproductive rates of critically-endangered gorillas (*gorilla gorilla*) has made the impact of Ebola especially concerning (Leroy et al. 2005).

Outbreaks have been detected in great apes prior to human outbreaks; thus, monitoring the health of Great Apes may provide a sentinel value for anticipating human outbreaks and employing risk mitigation strategies in people for public health, as well as early detection to promote timely disease control measures for wildlife conservation (Rouquet et al. 2004). The conservation community (such as park rangers and wildlife veterinarians) and public health experts can form tangible collaborations to improve understanding of Ebola and other diseases and find solutions. Doing so may require involvement of a much wider community. For example, several outbreaks have been definitively linked to hunting or butchering of wildlife for consumption. Wild species provide an important source of subsistence nutrition for some communities, but certain species, including non-human primates, are especially high risk for disease. In Central Africa hunters have been involved in reporting of wildlife carcasses to aide in disease investigation and detection of potential outbreaks, ideally before they occur in people so that risk mitigation strategies (i.e. not hunting certain species, not harvesting deceased animals) can be employed (CBD-WHO 2015; Rouquet et al. 2004).

Veterinary Pharmaceuticals

Vultures provide a critical ecosystem service: the scavenging of carrion, which helps prevents contamination of water and food sources that humans depend on. The use of the nonsteroidal anti-inflammatory drug (NSAID) Diclofenac for veterinary purposes in South Asia was linked to a collapse in *Gyps* vulture populations in the early 2000s. Vultures feeding on cattle and buffalo carcasses that had been treated with Diclofenac experienced toxicity resulting in renal disease and death, with vulture population declines of more than 95% over a decade (Green et al. 2004). The severe decline (estimated at tens of millions of vultures) had ecological impacts in the region with health implications. Feral dog populations served as a replacement for scavenging, leading to rise in the threat of human rabies cases. The lack of vultures at carcass sites also promoted conditions suitable for pest animals such as rats, presenting additional disease risks (Swan et al. 2006).

Although diclofenac was used widely in the region, the NSAID meloxicam provides an alternative therapeutic with low toxicity risk to vultures, and thus was promoted for use instead of diclofenac (Swan et al. 2006). India has since implemented regulations against the veterinary use of diclofenac, and vulture populations are slowly recovering. However, the overall weak consideration of environmental effects of veterinary licensing been demonstrated in other regions, with Spain's licensing of diclofenac for veterinary purposes in 2015 raising concerns about threats to vultures in Europe (Margalida et al. *Science* 2015), and there are grave concerns over the future of several vulture species in Africa, due to unintentional and intentional poisoning (mainly by poachers intent on avoiding the telltale signs of circling vultures over the carcasses of poached mammals).

Discussion points

1. What are examples of individual, socio-economic and environmental determinants of health in your own community?
2. Change to ecosystems can be broken down by their broad drivers (e.g. global climate change) and country or community-specific drivers (such as conversion of undisturbed forest to monocultures). Please think of examples of the types of ecosystem change occurring in your nation and how they may potentially have near and long-term health outcomes.
3. Consider a current or anticipated health issue related to degraded ecosystems. What sector(s) could be involved in finding solutions? What are some examples of possible solutions?

4. How can more integrated approaches that go beyond human health, such as One Health or Planetary Health, be implemented through policies and practices? Give examples for application through local, national and global levels and their potential outcomes.

Annotated bibliography

- The Millennium Ecosystem Assessment. 2005. "Ecosystems and Human Well-Being. Health Synthesis." http://www.who.int/globalchange/ecosystems/ecosystems05/en/ *Defines provisioning, regulating, supporting and cultural ecosystem services relevant to health.*
- Costanza and Mageau. 1999. "What is a healthy ecosystem?" *Aquatic Ecology*. 33:105-115. *This article considers health in relation to ecological resilience. It is somewhat preliminary (i.e. proposing relationships rather than empirically tested) but raises insightful ideas and is a concise synthesis.*
- World Health Organization and Convention on Biological Diversity. (2015). Connecting Global Priorities: Biodiversity and Human Health, a State of Knowledge Review. Retrieved from Genève and Montréal. *This extensive state of knowledge review looks at the links between biodiversity and health, but also brings in application to wider ecosystems, people and socioeconomic processes. Food and nutrition, water, air quality, noncommunicable diseases, infectious diseases are considered alongside several other key health topics. Areas of integration with the Sustainable Development Goals, collaboration with other sectors, and tangible research needs and solutions are proposed.*
- Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A., de Souza Dias, B. F., . . . Yach, D. (2015). Safeguarding Human Health in the Anthropocene Epoch: Report of The Rockefeller Foundation-Lancet Commission on Planetary Health. *The Lancet,* 386(10007), 1973-2028. *This reference covers a wide range of challenges and failures on both planetary and human health fronts. It discusses key health effects of environmental change such as nutrition and food security, water resources, zoonotic diseases, air pollution, and extreme weather. It also lays out a number of recommendations for future action. The authors recognize the important crossroads of planetary health, human health, effective policies, economic growth, and equality.*
- *The Lancet* Series on Zoonoses, especially "Ecology of Zoonoses: Natural and Unnatural Histories". http://www.thelancet.com/series/zoonoses (in particular Karesh, W.B., Dobson, A.P., Lloyd-Smith, J.O., Lubroth, J., Dixon, M.A., Bennett, M., Aldrich, S., Harrington, T., Loh, E., Machalaba, C., Thomas, M.J., Heymann, D.L. (2012). Ecology of zoonoses: natural and unnatural histories. *Lancet, 380*(9857), 1936-1945). *The series of papers explains evolutionary and ecological dynamics of disease and highlights anthropogenic drivers of infectious disease emergence, with numerous examples, as well as tools and methods for predicting disease (for example, ecological niche modeling and surveillance programs such as the USAID Emerging Pandemic Threats PREDICT project) as well as the role of social science in infectious disease research.*
- OIE. 2014. "One Health". *Scientific and Technical Review. Ed*. W.B. Karesh. 33(2). *Edition highlighting the One Health concept. Papers cover topics on food security, food*

safety, biodiversity, and climate change, as well as historical and current initiatives at the human-animal-environment interface. Specific diseases are also reviewed from a One Health perspective, and opportunities for tools and potential partners to engage in One Health are introduced.

- Machalaba, C., Romanelli, C., Stoett, P., Baum, S. E., Bouley, T. A., Daszak, P., & Karesh, W. B. (2015a). Climate Change and Health: Transcending Silos to Find Solutions. *Ann Glob Health, 81*(3), 445-458. doi:10.1016/j.aogh.2015.08.002. *This reference reviews and distinguishes the health effects of the upstream drivers of climate change and the outcomes of climate change and the opportunities to intervene on both. It examines opportunities for cross-disciplinary collaboration to address the challenge of unprecedented pressures on our environment and the resulting health implications. The paper provides examples of how policy makers and technical researchers from environment and other biodiversity communities, the health sector, and others can come together to find innovative solutions. Initiatives including REDD+ and Future Earth are mentioned.*

Recommended websites

- The World Health Organization Environmental Health website: http://www.who.int/topics/environmental_health/en/

- UNEP's Healthy Environment, Healthy People: Thematic Report, Ministerial Policy Review Session United Nations Environmental Assembly-2: http://www.unep.org/about/sgb/Portals/50153/UNEA/K1602727%20INF%205.pdf

- KVF Jubb Fellowship Lecture by Prof. Ted Leighton "Wildlife Health in the 21st Century" covering habitat loss, ecological processes and ecosystem resilience, biodiversity, food security, climate change: https://soundcloud.com/fvasunimelb/wildlife-health-in-the-21st-century-the-kvf-jubb-fellowship-public-lecture
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- EcoHealth Alliance: Examples of environmental health programs demonstrating One Health in action: http://www.ecohealthalliance.org/programs
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- *The Lancet* Commission on Planetary Health launch presentation by Sir Andy Haines https://www.youtube.com/watch?v=nWDRK3A2enM
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- Peter Daszak at TedMED 2010 presenting on disease risk from the wildlife trade and approaches to form synergies that promote pandemic prevention, biodiversity and ecosystems: https://www.youtube.com/watch?v=cPFGX7t4KJE

- Howard Frumkin at TedxRainer presenting on "Healthy Human Habitats" in 2010, emphasizing the built environment in relation to non-communicable diseases and opportunities for more sustainable and healthy solutions: https://www.youtube.com/watch?v=UfmR0LPfBX8

Module 10: Climate Change

Expected Learning Outcomes: upon completion of this module, students will be able to:

- identify the components and flows of the climate system
- understand the importance of the climate system for human well-being
- understand climate change at a basic level and as a social-ecological system
- understand the characteristics of climate that make it complex and adaptive
- discuss the challenges to climate change mitigation as well as some of the proposed solutions
- apply concepts of adaptive governance and ecosystem based management to discussion of climate change in general and through localized examples

Climate Change and its Global Importance

We move now even greater systems complexity. The climate system is made up of the atmosphere, land surface, snow and ice, oceans and water bodies, and the biosphere. Complex bi-directional exchanges of water, energy, and carbon within and between these components redistribute global heat and determine climate at the global, regional and local scales (Le Treut et al., 2007).

Shortwave energy from the sun enters our atmosphere and is absorbed or reflected by atmospheric gases as well as by the earth's surface. The earth re-emits the absorbed energy as longwave (or heat) energy. The gases in the atmosphere prevent some of the outgoing longwave energy from escaping to space. This "greenhouse effect" provides insulation and is responsible for maintaining habitable conditions on the planet. However, the anthropogenic causes of climate change – the human activities that add greenhouse gases to the atmosphere – are disrupting the system in multiple ways.

Though there are exchanges within and between components of the climate system, the greenhouse effect maintains a net radiation balance so that global surface temperatures are constant. The only way to significantly increase or decrease this net radiation balance would be to: 1) increase incoming solar radiation from the sun; 2) alter the reflectivity (known as albedo) of the atmosphere or earth's surface so that the amount of solar radiation being absorbed is decreased (as in the case of higher albedo, which results in net cooling) or increased (as in the case of lower albedo, which results in net warming); or 3) to alter the amount of longwave radiation emitted from the earth that reaches space, by changing greenhouse gas concentrations. The latter is responsible for current global warming and associated climate change.

Only some of the gases that make up our atmosphere are greenhouse gases. The two most significant of these are water vapour and carbon dioxide (CO_2). Since approximately 1750, we have been contributing additional carbon (in the form of carbon dioxide) to our climate system from the burning of fossil fuels and from deforestation (Le Treut et al., 2007). Climate scientists use climate models to try to determine how the system will respond to these additional carbon inputs to the atmosphere. Climate models are simplifications of the earth's components and of the exchanges of energy, water and carbon between them (Le Treut et al., 2007). They rely on "scenarios" of future energy use, technology development, population growth, and income per capita as well as calculations of earth system processes and feedback loops to estimate potential radiative forcing from current and future emissions and associated climatic responses (Van Vuuren et al., 2011).

Climate and weather cuts across all the ecosystem services we have emphasized in this course. With provisioning services, many communities rely on a reliable progression of seasonal weather (maintained by large-scale climatic processes) as the basis for food harvesting and processing activities (Berkes, 2012; Turner & Clifton, 2009; Turner et al., 2006); world climate zones are significant determinants of agriculture. Together with physical landscape, climate determines biome existence, associated ecosystems, and related food viability (Agrawal et al., 2001). Regulating services are significant: carbon sinks (oceans, sediments and forests that uptake carbon from the atmosphere and store it) are recognized as an ecosystem service (Alcamo et al., 2003; Fisher et al., 2009). Climate even regulates human diseases: as discussed in the previous chapter, shifting temperature and precipitation patterns will re-distribute disease vectors and alter exposure and vulnerability to human pathogens (Githeko et al., 2000; Kovats et al., 2001), as well as the prevalence of plant/livestock pests and diseases (Anderson et al., 2004; Rosenzweig et al., 2001). The timing of pollination and other phenological processes are dependent on climate (Giannini et al., 2012; Kjøhlet al., 2011; McCarty, 2001; Turner & Clifton, 2009). Global shifts in temperature are also fuelling extreme weather events (Field et al., 2014).

Cultural services are clearly affected as well: many religions attach spiritual and cultural values to weather processes (e.g. Berkes, 2012; Byg & Salick, 2009; Salick & Byg, 2007; Turner & Spalding, 2013) and traditional knowledge systems are rooted in the harvesting and cultural significance of reliable weather patterns (e.g. Berkes, 2012; Berkes & Jolly, 2002; Byg & Salick, 2009; Salick & Byg, 2007; Turner & Spalding, 2013). Some Indigenous groups identify with the weather and its seasonal progression as important to their oral narratives, their food harvesting activities and valued foods (including cultural keystone species), and even their belief systems (e.g. Berkes, 2012; Berkes & Jolly, 2002; Byg & Salick, 2009; Turner & Spalding, 2013). Small island states are in danger of complete disappearance due to sea level rise.

While it is obvious that climate change is having an impact on the material dimension, there are also serious repercussions for the relational and subjective dimensions. For example, some Indigenous cultural practices are becoming less viable as a lack of predictability makes it difficult to plan for and carry out cultural events depending on environmental conditions (Berkes, 2012; Salick & Byg, 2007). This is true of non-Indigenous cultural practices as well (e.g., warmer winters are making outdoor ice skating and hockey less and less viable in Canada; Damyanov et al., 2012). Feelings of guilt, hopelessness, despair, and anxiety surrounding climate change can overshadow the need for more hopeful messages to be passed on to children (Fritze, 2008).

Climate Change as Complex Adaptive System

The climate system is open, complex and self-organizing. The natural greenhouse gas effect serves to trap some of the outgoing longwave radiation for a balanced energy budget over time, and the albedo effect from atmospheric clouds and light-colored surfaces such as the polar ice sheets and glaciers reflect incoming solar radiation to avoid warming (Le Treut et al., 2007). Meanwhile, the uneven distribution of solar radiation from the equator to the poles results in differences in air pressure, precipitation, ocean water temperature and salinity, which drive complex processes such as large-scale and regional atmospheric circulation and ocean currents (see Chapter 10). Atmospheric processes influence and are influenced in turn by land vegetation processes such as photosynthesis and deforestation or forest fires; ocean processes such as primary productivity, carbon uptake, evaporation, and water temperature; and build-up and melting of sea ice, ice sheets and glaciers.

Feedback loops are one way for the climate system to self-regulate. An important example is the thermodynamic law that allows the earth to radiate longwave energy to space in direct proportion to its temperature, which allows the planet to avoid over-heating in the case of an increase in radiative forcing. (Amazingly, the earth has maintained a relatively constant temperature despite the 25 percent increase in solar radiation over the past 3.5 billion years). Clouds are another example of a feedback mechanism, acting as both positive and negative feedback: by absorbing some of the outgoing longwave radiation, they contribute to warming. In reflecting some of the incoming solar radiation, however, they contribute to cooling, and they actually have a net cooling effect in the system. In the presence of unexpected inputs of carbon to the atmosphere, however, feedback loops can also be responsible for an overall de-regulation of the climate system. Water vapor forms from the evaporation of water from the surface to the atmosphere, and is an important greenhouse gas that depends entirely on the temperature of earth's surface and lower atmosphere. Since warmer temperatures lead to increased transport of water vapor to the atmosphere, the greenhouse effect will contribute to and be amplified by warming temperatures.

The ice albedo feedback occurs when melting sea ice causes the surface area at the poles to become increasingly dark-colored, due to the disappearance of the white-colored ice. More solar radiation is absorbed rather than being reflected, and temperatures warm faster, leading to accelerated ice melt. The carbon cycle feedback results because higher global temperatures are actually less conducive to speedy carbon uptake from our planet's oceans and forests. Increasing CO_2 inputs to the atmosphere result in warming which results in a decreased capacity for carbon sequestration from our carbon sinks, which in turns leads to more warming.

The methane permafrost is another potential and disconcerting example of a positive climate change feedback loop. Methane is a potent greenhouse gas, and there are currently 400 gigatons of carbon equivalent of methane locked into the arctic permafrost (our atmosphere currently only has 3.5 gigatons of carbon equivalent of methane). Additional warming could trigger the release of some of this methane from the permafrost, which would lead to a rapid increase in warming and additional release of methane stores.

If these feedback mechanisms were not in place, global warming would continue to be roughly proportional to the amount of carbon dioxide being emitted. However, scientists believe that the presence of these feedback loops could lead to **'thresholds' or 'tipping points'** wherein a small change past a significant threshold could result in a disproportionate amount of warming and associated climate system response (Lenton et al., 2008). It is understood that changes in climate already contribute to major ecosystem regime shifts in coral reefs, woodlands, deserts, and oceans. Should climatic tipping points be triggered, there is potential for there to be a major shift in these ecosystems and in the climate system in general. The increase in freshwater to the North Atlantic from melting polar ice, for example, could trigger a deceleration in the transport of warm ocean water from lower latitudes to Eastern North America and Western Europe, resulting in substantially colder temperatures (Scheffer et al., 2001).

Even in the absence of major regime shifts, the impacts of increasing levels of CO_2 and escalation in global temperatures are numerous and complex. Examples include global re-distribution of precipitation patterns (and associated drought, desertification, flooding and landslides), sea-level rise, increased risk to biodiversity from land and ocean habitat loss, increased vulnerability of food crops to pests and diseases, increased intensity of extreme weather events, more frequent and severe heat waves, ocean acidification and associated effects on ecologically important marine species, and changes to ice landscapes (Field et al., 2014).

Though it may sound more like a natural process, the carbon cycle is actually an example of a social-ecological system. The natural carbon cycle is a process whereby carbon is cycled between ocean, atmosphere, lithosphere, and terrestrial ecosystems through processes on timescales ranging from a single day to millions of years. Because the recent addition of carbon dioxide to the atmosphere depends on human socio-economic activities, and because these socio-economic activities will be affected by resulting changes to the climate, humans are now an interactive component of the earth's carbon cycle and scientists are striving to understand the complex interactions between complex human processes and complex earth processes (Falkowski et al., 2000). Indeed, most of the complexity of climate change stems not from the interacting physical components but from the human component. Driving the human component are a myriad of complex social, economic, and political processes that are impossible to model. Scientists have relied in the past on "emission scenarios" to detail possible combinations of future circumstances, energy economies, and climate change policy to identify a range of future outcomes based on this component (IPCC, 2000).

Scale plays a major role in how we perceive climate change and its drivers. Climate has changed significantly over timescales of billions, millions, or thousands of years. Additionally, the physical processes of climate change span many temporal and spatial scales. Climate varies over timescales of years or decades due to natural variability and phenomena such as the El Nino Southern Osillation or the Northern Oscillation, which are regional shifts in climate regime normally triggered by subtle changes in air pressure distribution over the globe and accompanying changes in circulation and temperature distribution. However, anthropogenic climate change is unique in that significant and enduring changes are occurring over decades

(IPCC, 2013). The interaction between the climate system and the human component is bi-directional but depends on the scale at which we view it. Some feedback will be relevant only when viewed at a certain scale. For instance, a single subsistence community may view climate change as a unidirectional force whose impacts on their ecosystem and ways of life are external to their control. Alternatively, to mitigate climate change at the global level, concerted global action must be taken. The ability of a single community or even a single nation to decelerate global warming is low, but when viewed at the global scale humans collectively are the driving force, and the climate system is the impacted entity (Vitousek et al., 1997). This reinforces the need to work across sectors to cope with the changes we are already seeing take place.

Frameworks for Climate Change Action- managing both sides of the system

The UN General Assembly adopted the Sustainable Development Goals in 2015, and Goal 13 is dedicated to climate change:

Goal 13. Take urgent action to combat climate change and its impacts*

13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
13.2 Integrate climate change measures into national policies, strategies and planning
13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning
13.a Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible
13.b Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities

* Acknowledging that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change.

Within this context, climate change should be seen a particularly wicked problem (Lazarus, 2008; Rittel & Webber, 1973), demanding concerted action that will affect billions of actors. Though pockets of ideological opposition exist, it is generally recognized worldwide as a primary threat to ecosystem health and human livelihood alike, with diffused responsibilities for its historical causes. The “2-degrees target” above pre-industrial levels has been widely accepted since the 1996 as the “maximum allowable warming to avoid dangerous anthropogenic interference in the climate”, and was listed as the desirable temperature target in the Copenhagen accord of 2009 (Randalls, 2010). On one hand, this temperature target has been criticized because it is too ambitious and would require too many economic sacrifices (Klein, 2014). On the other hand, policy-makers now recognize that the 2-degree world could still have dangerous consequences for many nations and island-states, and that a target of 1.5° C is more desirable. (UNFCCC, 2015) There are complex social justice issues surrounding the question of burden versus responsibility. Those that are most vulnerable or are facing the greatest exposure to climate change impacts (e.g. developing countries and small island developing states, Indigenous and subsistence communities) are least likely to have contributed to historical global emissions (Field et al., 2014; Stoett 2012)

Political solutions remain elusive, even after the historic Paris Agreement of 2015. Technological solutions to climate change, or "technofixes", are often discussed as mitigation measures. These include the use of alternative energy and fuel sources, and geoengineering measures like artificially enhancing the planetary albedo effect and removing carbon dioxide from the atmosphere. Measures such as these may prove useful if they can feasibly and safely be employed within the next decade, but we cannot rely on them as the solution to this problem. Technofixes ignore the root causes of the issue and treat climate change as occurring in a vacuum with no other social, environmental, political, or economic cofounding factors.

Economic mechanisms such as the carbon market and carbon tax are designed to curb greenhouse gas emissions without challenging the economic system from which they stem. In treating carbon emissions as a commodity, several industries have taken advantage of loopholes in order to generate millions of dollars without taking real measures to decrease their emissions. Meanwhile, carbon offset programs are increasingly responsible for the displacement of local and Indigenous communities from their homes and territories in order to preserve these carbon sinks. Examples like these demonstrate that with economic mitigation mechanisms, there are clear winners and losers, often the same winners and losers that have always resulted from our dominant economic paradigm of free-market capitalism (Klein, 2014).

Other mitigation mechanisms are aimed at increasing our global carbon sinks, addressing emissions by sector, and encouraging a shift toward renewable energy. We mentioned (Reducing Emissions from Deforestation and Forest Degradation) in the module on Forests. Another effort is the Clean Development Mechanism (CDM), defined in Article 12 of the Protocol, which "allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries. Such projects can earn saleable certified emission reduction (CER) credits, each equivalent to one tonne of CO_2, which can be counted towards meeting Kyoto targets. The mechanism was seen by many as a trailblazer. It is the first global, environmental investment and credit scheme of its kind, providing a standardized emissions offset instrument, CERs. A CDM project activity might involve, for example, a rural electrification project using solar panels or the installation of more energy-efficient boilers. The mechanism stimulates sustainable development and emission reductions, while giving industrialized countries some flexibility in how they meet their emission reduction or limitation targets." (UNFCCC, 2014). However these approaches have their own limitations and are often accused of paving the way for richer industrialized countries to continue with "business as usual" while putting undue emphasis on developing countries to seek solutions (Gupta 2010).

The Paris Agreement at COP21 was very well received after it ambitiously resulted in a new temperature target of 1.5°C to avoid dangerous climate change impacts in vulnerable populations. The Agreement will become legally binding if 55 countries that collectively produce at least 55% of world GHG emissions ratify the agreement by April 21 2017. Parties agreed that the international community would provide an annual $100 billion to developing countries for mitigation and adaptation measures. Potential outcomes of concern are that the US will refuse to ratify and thus greatly diminish the chances of it becoming legally binding to the signing Parties. Additionally, the goal of zero emissions in the second half of the 21st century falls short of limiting temperature rise to 1.5°C. Finally, the collective national reduction commitments of all the parties would result in more than 2°C warming, and therefore these commitments would be insufficient even if the Agreement were ratified. In spite of these drawbacks, the spirit of cooperation, participation and progress at these meetings has been well received (Hulme, 2016; Rhodes, 2016).

Adaptive governance and ecosystem based adaptation

Adaptive governance has been identified as a possible way forward for countries to meet their emissions reduction targets. Such a governance framework would "[factor] the global problem into thousands of local problems, each of which is more tractable scientifically and politically than the global one and somewhat different." (Brunner & Lynch, 2013, p. viii). Adaptive governance would allow for local policy solutions that make use of available resources, tie in with community needs and values, and decentralize responsibility for climate change mitigation and adaptation from governmental policy-makers and industries. One important tool in adaptive governance could be ecosystem based adaptation (EBA), which "incorporates biodiversity and ecosystem services into an overall adaptation strategy to help people to adapt to the adverse effects of climate change" (CBD, 2009).

EBA is a means of harnessing and nurturing characteristics of existing ecosystems to amplify the effectiveness of adaptation measures with minimal additional effort or infrastructure. In promoting healthy ecosystems, communities can greatly increase the resilience of their social-ecological systems against stressors (Munang et al., 2013). Successful EBA approaches promote climate change mitigation and adaptation, support socio-economic development, protect ecosystems and biodiversity, and encourage sustainable economic development. EBA can take many forms and can include the restoration of fragmented or degraded natural areas, the protection of groundwater recharge zones, the restoration of floodplains, and the reinforcement or protection of barrier-type infrastructure such as coral reefs, mangroves, and forests that provide a buffer from environmental extremes. Despite these benefits, the potential of EBA is not currently recognized by most national governments (Munang et al., 2013). However, the United Nations Environment Programme (UNEP) is providing support for EBA projects in individual communities world-wide, which will provide governments with examples of the successful joint implementation of EBA with broader policy strategies (Lo, 2016).

In addition to adaptive governance and the use of ecosystem based adaptation, many communities around the globe are calling for direct changes to the current economic framework. Free-market capitalism allows for little regulation or control over multi-national corporations and trade, and under this framework it is difficult for governments to intervene in corporate activities if such interventions restrain profit. (Klein, 2014) People are calling for a framework that does not prioritize multi-national corporations over the health of our global social-ecological system. Environmental and social justice movements such as Occupy Wall Street, the DeGrowth Movement, the Fossil Fuel Divestment movement, and the Leap Manifesto all encourage a shift away from free-market capitalism and toward investment in clean energy, health, and the environment. These movements call for the recognition of our social-ecological system as an interdependent system comprising our ecosystems, economy, societies, and cultures, and raise questions about prioritizing economic profit at the expense of human health, safety, and economic security.

Case Studies

The Inuit in Sach's Harbor, Northwest Territories, Canada

Climate change, and the need for adaptation, is not a future scenario for people in fragile ecosystems such as the Arctic, as a rapidly increasing number of studies suggests. One study focuses on Inuvialuit vulnerability and adaptation to climate change in Sach's Harbor. It categorizes adaptive capacity into short term "coping mechanisms" and long-term "adaptive strategies". Impacts of climate change in this subsistence community, such as melting sea-ice or increasingly unpredictable weather, restrict Inuvialuit access to traditional foods; impair safety when hunting, fishing, or travelling on the land and water; damage Inuvialuit reliance on traditional knowledge to predict weather or the behavior or condition of plant and animal species; and affect species availability in unexpected ways. Examples of coping mechanisms were waiting for safe conditions before travelling on the ice; fishing other lakes when access to their traditional sites was barred by slumping; using all-terrain vehicles instead of snowmobiles; increased monitoring of environmental conditions; and including non-traditional foods in their diet. Long-term adaptive strategies include distribution of resources among groups, flexibility in resource harvesting cycles and use of oral tradition to respond adaptively to change; diversification of knowledge and skill sets; food sharing; and intercommunity trade.

Coping mechanisms tended to be smaller, and adaptive strategies larger, on both temporal and spatial scales. Additionally, the Inuvialuit Final Agreement of 1984 created a framework for multiple cross-scale linkages between the community and the regional Inuvialuit government, the territorial government, and the federal government, which provides support for and flexibility of adaptive responses to environmental feedback on a multitude of interconnected temporal and spatial scales. This case study is therefore a good example for issues of social-ecological resilience; adaptive capacity; scale; and adaptive governance in regards to climate change.

Source: Berkes & Jolly (2002) Adapting to climate change: Social ecological resilience in Canadian Western Arctic community

Sundarbans Region, India and Bangladesh

"The Sundarbans region along the coast of India and Bangladesh has the largest expanse of contiguous mangrove forests in the world, stretching for 10 000 km^2 along the coast. Aside from coastal protection, the mangroves in the Sundarbans provide nursery habitat for fish and other animals and supports other important ecosystem services. In recognition of this unique, biodiverse wetland ecosystem, the Indian portion is designated as a World Heritage Site, while the Sundarbans Reserved Forest in Bangladesh is a designated Ramsar site. The Sundarbans are prone to severe cyclones and storm surges. Cyclone Sidr in 2007 killed 3500 people and affected millions more. IPCC projections show that the severe weather events will increase as temperatures and sea levels rise (IPCC 2012), making the Sundarbans region even more vulnerable in the future.

EbA (ecosytem-based adaptation) and Eco-DRR (Disaster Relief and Reduction) measures in the Sundarbans include protection and management of mangrove ecosystems, reducing their vulnerability to climate change and sea level rise and enabling this highly populated area to benefit from coastal protection. Other EbA measures include community-based afforestation of coastal zones, and mangrove restoration (Rahman 2014). For decades, afforestation and restoration activities in the Sundarbans have helped conserve endangered species and protect people from cyclones and storms (MacIntosh et al. 2012).

It would cost comparatively more to build hard infrastructure to protect the coastline. Estimates place costs to build coastal embankments, built to offer the same extent of protection as the mangroves, at USD$294 million in capital investment, and USD$6 million each year in maintenance (Colette 2007). In light of the multiple benefits to people from protection of mangroves, EbA approaches in the Sundarbans provide examples of low-regrets strategies to reduce climate change vulnerability and disaster risk for people."

Source: Protection and rehabilitation of degraded mangrove forests of the Sundarbans (Lo, 2016: Experiences with Ecosystem Based Adaptation and Disaster Risk Reduction, p.30)

Discussion points

1. After calculating your personal carbon footprint using the link provided [see Carbon footprint calculator http://www.carbonfootprint.com/calculator.aspx], discuss your results while bearing our social-ecological system in mind. How does your footprint compare to the average for developed and developing countries? What factors in your nation's social, political, or economic system influence your own footprint?
2. Pick a scale (local or global) and draw a short list of examples of (1) the climate system impacting human systems and (2) human systems impacting the climate system. Which list is longer? How does this relate to issues of climate change mitigation and adaptation?
3. Go to the Solutions project website using the link provided [in the resources below] and take a look around. Then go to "resources" → "139 countries 100% infographics", and download the infographic for your country. Pick one energy source from the 2050 projected energy mix and its relative percentage of future energy production according to this info graphic. How would this energy source fit into the larger picture of your country's social ecological system? What ecosystems, economic, and social or cultural factors could be involved?
4. What would adaptive climate change governance look like in your own community? What initiatives would be involved? What resources would be

needed? How could your community or city's economic, social, and environmental resources be improved?

5. What is an example of an eco-system based adaptation in your immediate or surrounding ecosystem that could prevent damage or loss from the impacts of climate change?

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Klein, N. (2014). *This Changes Everything: Climate Change vs. the Climate*. New York: Simon and Schuster. *Naomi Klein explores the historical context for free-market capitalism and its inherent conflict with mitigation policy, and searches for alternatives through case studies of healthy social-ecological systems and social and environmental justice movements around the world.*

Stoett, P. J. (2012). *Global Ecopolitics: Crisis, Governance, and Justice*. Toronto: University of Toronto Press. *Explores green thinking and international relations between states including the need to integrate justice issues with reform.*

Turner, C. (2008). "The Geography of Hope: A Tour of the World We Need." (1st Edition). Vintage Canada. *Chris Turner turns away from doom-and-gloom mitigation scenarios to tour communities where people are governing and caring for their social-ecological systems in* *decentralized and sustainable ways, with positive results for environment and economy. In harnessing the natural functions of their surrounding environment, they make climate change mitigation and adaptation look easy, a message that this book and EBA have in common.*

Turner, N., & Spalding, P. R. (2013). "We Might Go Back to This"; Drawing on the Past to Meet the Future in Northwestern North American Indigenous Communities. *Ecology and Society*, 18(4). http://doi.org/10.5751/ES-05981-180429 *An exploration of the contributions of Traditional Ecological Knowledge systems to contemporary climate change understanding and to Indigenous resilience and adaptation to climate change.*

Recommended websites

Carbon footprint calculator http://www.carbonfootprint.com/calculator.aspx

Countdown clock to 2°C http://countdown2degrees.com

Documentary This Changes Everything http://thefilm.thischangeseverything.org/

Documentary People of the Ice https://www.nfb.ca/playlists/unikkausivut-sharing-our-stories/viewing/people_of_the_ice/

Documentary Washed Away https://www.nfb.ca/film/washed_away

Documentary Climate on the Edge https://www.nfb.ca/film/climate_on_the_edge

Leap Manifesto https://leapmanifesto.org/en/the-leap-manifesto/

NASA Interactive climate time machine http://climate.nasa.gov/climate_resources/25/

National Geographic Simplified map global climate change impacts for ecosystems and populations http://environment.nationalgeographic.com/environment/global-warming/gw-impacts-interactive/

RealClimate climate change blog http://realclimate.org/

Solutions Project Website http://thesolutionsproject.org

Video UNEP Coastal Ecosystems as barriers to climate change https://www.youtube.com/watch?v=DoYNMjhZCFY&index=3&list=PLZ4sOGXTWw8Fltp4qv7KfrTqdcNMnPm-V

Module 11: The Advanced Certificate Option

The Assignment

As explained the preface to this sourcebook, the EAST MOOC is designed to enable students to cover a wide variety of material related to systems thinking and the ecosystem approach to solving wicked problems. But we have added a more demanding assignment section, the Advanced Certificate, for students who want to push themselves a little further and utilize the knowledge they have acquired in the course so far. This is particularly apposite for teachers who are offering this MOOC as part of a blended learning course. There are a number of ways to assign students an extra task, and we will suggest one here: an assignment that will be both intellectually challenging and topical, and which will relate to the individual context of the student. But the assignment could be approached via a number of interesting ways. For example, in a blended course with classroom time, teachers could ask for a team or individual presentation. Teamwork is always an interesting challenge for students: for example, they could be asked to put together a joint video presentation that could then be uploaded to You Tube channels. However, we will describe an assignment here that can apply to those students who will be taking the course entirely online and for whom teamwork would be difficult. How individual teachers reframe the assignment is entirely up to them.

For the advanced certificate, here is the assignment:

Develop a response to the following question, and present your finding in an essay of between, 3,000-3,500 words (not including references).

The question: **Using the knowledge you have gained in this course, choose one of the UN Sustainable Development Goals that were adopted by the UN General Assembly in 2015, and apply systems thinking and the ecosystem approach to develop a strategy to meet the goal. Apply the issue to your own specific context – your community, country, occupation, social status, or whatever other forms of self-identification you wish to apply.** There are numerous sources describing and explaining the SDGs for students, and they should be encouraged to engage in a bit of background reading.

Here is a summary of the process offered by the UN:

Since the 1972 UN Conference on the Human Environment the reach of sustainable development governance has expanded considerably at local, national, regional and international levels. The need for the integration of economic development, natural resources management and protection and social equity and inclusion was introduced for the first time by the 1987 Brundtland Report (Our Common Future), and was central in framing the discussions at the 1992 United Nations Conference on Environment and

Development (UNCED) also known as the Earth Summit. In 1993 the General Assembly established the Commission on Sustainable Development (CSD), as the United Nations high level political body entrusted with the monitoring and promotion of the implementation of the Rio outcomes, including Agenda 21.

The 2002 World Summit on Sustainable Development advanced the mainstreaming of the three dimensions of sustainable development in development policies at all levels through the adoption of the Johannesburg Plan of Implementation (JPOI).

A process was created for discussing issues pertaining to the sustainable development of small island developing States resulting in two important action plans - Barbados Plan of Action and Mauritius Strategy. The Third International Conference on Small Island Developing States, which was held in 2014, took these processes forward and provided the SAMOA Pathway.

In 2012 at the Rio+20 Conference, the international community decided to establish a High-level Political Forum on Sustainable Development to subsequently replace the Commission on Sustainable Development. The High-level Political Forum on Sustainable Development held its first meeting on 24 September 2013. At the Rio+20 Conference, Member States also decided to launch a process to develop a set of Sustainable Development Goals (SDGs), which were to build upon the Millennium Development Goals and converge with the post 2015 development agenda.

The process of arriving at the post 2015 development agenda was Member State-led with broad participation from Major Groups and other civil society stakeholders. On 25 September 2015, the United Nations General Assembly formally adopted the universal, integrated and transformative 2030 Agenda for Sustainable Development, along with a set of 17 Sustainable Development Goals and 169 associated targets.

Source: https://sustainabledevelopment.un.org/intergovernmental

The 17 SDGs (which effectively replace the Millennium Development Goals) are as follows:

Goal 1. End poverty in all its forms everywhere
Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
Goal 3. Ensure healthy lives and promote well-being for all at all ages
Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
Goal 5. Achieve gender equality and empower all women and girls
Goal 6. Ensure availability and sustainable management of water and sanitation for all
Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
Goal 10. Reduce inequality within and among countries
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Goal 12. Ensure sustainable consumption and production patterns
Goal 13. Take urgent action to combat climate change and its impacts*
Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice

for all and build effective, accountable and inclusive institutions at all levels
Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development

Please note, however, that each Goal encompasses several specific targets. They can all be found here: https://sustainabledevelopment.un.org/post2015/transformingourworld

Students should choose a Goal that interests them and a more specific target of that Goal, and complete their assignment with explicit reference to the application of the ecosystem approach. Of course, not all the targets lend themselves easily to an ecosystem approach, but the targets related directly to the environment (such as Goals 6,7, 11, 12, 13, 14, and 15) are not the only ones that should encompass an ecosystem approach in related strategies. We've argued in this course that it will be beneficial in most sectors to take ecosystems into account. We've also contended that it is time to engage in cross-sectoral thinking when engaging in ecosystem management. As a recently published UNEP brochure asserts:

"UNEP recognizes that sectoral approaches to managing natural resources are often failing to protect them from pollution, depletion, and exploitation. These approaches treat the environment and development as independent parts, managed by separate institutions and governed by sectoral laws. UNEP supports an integrated approach to ecosystem management which sees the environment as a complex web of connected parts that requires a more holistic approach from institutions, law and practices."

Avoiding the classic and inefficient tug-of-war between sectors is an essential component of an ecosystem approach. Please bear this in mind when pursuing the Advanced Certificate project, and think creatively about how a multi-sector approach can help reach your goals. Efforts need not be limited to actions taking place within one country, either. For example, African leaders have collaborated on the Landscapes for People Food and Nature (LPFN) Initiative, which includes the African Landscapes Plan, which "provides policy and programme recommendations for national, regional, and international action, and a blueprint for how Africa can embrace integrated ecosystem management. Under the LFPN, experts, practitioners, businesspeople and leaders from across Africa share best practices in landscape management research and lessons learned from years of local and national policy initiatives on the continent."

Grading

While the modules in this course have permitted automated grading, this assignment demands more concerted focus for grading. Students taking this course in a blended environment, including classroom work, can be graded by the teacher of the course, but those finishing the course online through the MOOC will be graded by peer review. Each student will receive assignments written/composed by other students and will be asked to grade them (A, B, C, D or fail). Three peers will review each assignment and the average grade will prevail. A code for grading will be provided on the MOOC website.

Conclusion

It is our hope that this course will broaden the knowledge base of all participants, and that this assignment will give them a sense of the complexity inherent in working toward solutions that encompass human and natural systems. Nothing less than the welfare and, in many cases, the survival of future generations is at stake. Again, we welcome suggestions for improvements and additions to both this sourcebook and the UNEP EAST MOOC.

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Note: please see the annotated bibliographies offered at the end of each chapter for more sources; in some cases these sources are replicated here, but not in all.

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