Balancing Water for People and Nature

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INTRODUCTION

The recognition that not just people but also “nature” needs water has emerged a few decades ago. Yet the notions that on top of water people also need "nature", not just for recreation or inspiration, is relatively new. This paper argues (a) that nature is of survival value for people, and much of this is through its role in water provision; and (b) that in order to provide water, as well as other critical benefits to people, nature needs water too, and hence should be a legitimate water customer. The paper first explains how ecosystems are involved in providing water to people, and then explores how water resource development can interfere rather than assist in this process. Finally, means for mitigating the damages and striking a balance among people and nature are recommended.

NATURE, ECOSYSTEMS, BIODIVERSITY AND SERVICES

Nature and ecosystems

“Nature” is an elusive term. It can mean everything or nothing. When in the 1970s of the last century the 3-year program “The Structure and Function of Ecosystems” under the International Biological Program (IBP) was launched research sites were to be set in “natural” areas only. But it was rapidly realized that even the most pristine ecosystem, like for example the Tundra of Point Barrow, Alaska, is not any more “Natural”. This realization dawned on the scientific community more than a generation ago, and current trends and projections of population growth and its ecological footprint further strengthen it. Similarly, the notion that our nature reserves, national parks and other “protected areas” conserve nature is outdated, since conservation measures in themselves constitute “un-natural” interventions. All these speaks for the notion that “nature” means nothing. But the Man and Biosphere program that succeeded the International Biological Program molded the “Biosphere Reserve”, in which a gradient of naturalness and a gradient of human use go the opposite directions, from a small core under strict conservation and no human use, to a large periphery of little conservation and much human use. Thus the Biosphere Reserve strikes a balance of “nature” with “non-nature” or of environment with development, and represents an intermediate view of nature that is either nothing or everything. More recently, however, the Millennium Ecosystem Assessment (MA) has developed over the first 5 years of the new millennium the approach that “nature”, or the environment, is everywhere and natural processes occur that are significant to people occur in the few most pristine environments on earth, and in all the rest of the globe, even where human impact is the strongest. This notion replaces “nature” and “environment” with the term “ecosystem”, whereby ecosystems differ in the amount of “nature” they have. In thie paper, therefore, the term “nature” usually comes with inverted commas.

The term “ecosystem”, coined by practitioners of life sciences, applies to a landscape unit comprising all its organisms and the physical and chemical attributes of that landscape, some of which affect, are affected by, or interact with the organisms in that landscape unit. The network of interactions between the components of the ecosystem comprises its functioning. This definition is not new, but the MA was innovative in that among the global ecosystems such as forests, drylands and polar ones, cultivated and urban ecosystems are included too (MA 2005). This approach reflects the recognition that not only the latter two, but most other ecosystems on earth not only are affected by mankind, but they are also managed by people, either actively or passively. The actively managed ones now constitute more than half of the ice-free earth (11% of which are cultivated (Mooney et al. 1995).

Ecosystems and ecosystem services

Ever since the IBP program the notion that ecosystems provide (often marketable) "goods" and generate (valuable but priceless) "services" useful to humanity acquired momentum. It was often implicit that the above goods and service are provided by both human-managed and those still regarded as “natural” ecosystems, but the goods and services of the latter are provided free. Furthermore, it has been recognized that through provision of goods (such as food or medicinal plants) and services (such as soil development or aquifer recharge), “natural” ecosystems contribute to the sustainability of actively human-managed ecosystems and promote a sustainable human well-being. Therefore, when humans impair the provision of goods and services by ecosystems (then supposed to be either natural or passively managed), these must be replaced by artificial means. But these often turn out to be expensive and inferior to ecosystem-provided goods and servies (Cohen & Tilman 1996, Daily et al. 1997). Because natural ecosystems provide goods and services at no immediate financial cost, their value is underestimated or overlooked (Perrings 1995), what often brings about a non-intentional degradation in their provision. Therefore, for people to benefit from ecosystems' goods and services, they must be recognized, understood and protected (Costanza et al. 1997).

The MA, however, dramatically revised these notions in several ways. First, it defined "ecosystem services" as "benefits people obtain from ecosystems", what did away with the distinction between "goods" and "services", and incorporated the goods into services, which were classified into four major functional groups (Fig. 1). The Provisioning services are the "goods", either produced by ecosystems, like food (mostly provided by cultivated ecosystems but also by "natural" ones, like sea food) or freshwater that provided thought not produced by ecosystems. The Regulating services are the benefits obtained from regulation of ecosystem processes. These include the regulation of surface runoff and its velocity through the structure and architecture of vegetation, or water purification regulated by the activities of freshwater organisms in freshwater ecosystems. The Cultural services constitute the non-material benefits obtained from ecosystems, such as the recreation options so highly valued when provided from freshwater ecosystems, as well as spiritual, inspirational and aesthetic values many of these ecosystems provide. Finally, the Supporting services critical for the provision of all other services, derive from basic ecosystem function, such as primary production that generates the material basis for all life on earth, nutrient cycling that is tightly linked to it, and soil formation and conservation, instrumental in the infiltration of rainwater to aquifers. Finally and most important is the serves of supporting biodiversity.

Insert Figure 1 here

Ecosystems services and biodiversity

Biota and biodiversity

An indispensable component of ecosystems is their *biota*, meaning the assemblage of all living organisms within the ecosystem, and belonging to all micro-organisms, plant and animal species of which any given ecosystem is endowed. All these may be involved in one way or another, directly and indirectly, in ecosystem functions, most of which benefit people, again directly or indirectly. Thus, the biota as a whole may be involved in the provision of ecosystem services. But what is critical to the diversity, quality and the sustainability of this provision is not just the dimensions of the *biota* of the ecosystem, but the *diversity* within it. The term *biodiversity* thus has a deeper meaning than *biota* in the sense that while biota is a *structural* component of the ecosystem, *biodiversity* is more of a *functional* term, addressing the functionality of the ecosystem's organisms in service provision.

"Biodiversity" (shorthand for biological diversity) was defined by the 1992 United Nations Convention on Biological Diversity (CBD) as "*the **variability** among living organisms from all sources … terrestrial, marine, and other aquatic ecosystems …'* (Anonymous 1992). Thus, the term refers not only to the ecological notion of *species diversity* or to the genetically based variability either within or among species populations, but also to the quality, range or extent of *differences* between the biotic entities dwelling in a given ecosystem (Heywood & Bastge 1995). Thus, biodiversity is important not only as a "cultural" asset (i.e., directly providing cultural services), but mostly because apparently most of its components are directly and indirectly involved in providing the whole suite of ecosystem services.

Biodiversity and service provision

The issue of whether or not all species are instrumental in and essential for, the provision of ecosystem services and hence the question of the degree of species' losses that would not impair service provision is still unresolved. Examples of exotic species replacing indigenous species but apparently providing equivalent ecosystem services, may suggest that many species of "natural" ecosystems are redundant with respect to ecosystem service provision (Lawton and Brown 1993). Further studies, however, elucidated the circumstance under which species losses would significantly compromise service provision. This would happened when the lost species (a) has no apparent role in service provision but other species that do have a role depend on the lost species; (b) is a species of a species-poor ecosystem (Mooney et al. 1995); (c) is quantitatively dominant in that ecosystem; (d) differs strongly from other species in the ecosystem (e.g. the sea otter in marine coastal ecosystems, Power and Mills 1995). Also, a single individual species may not be tightly associated with service provision, but the service can be provided only when a large number of species, very different from each other (i.e. making a rich biodiversity) jointly function in providing this service.

The significance of rich biodiversity *per se* rather than that of individual species remain controversial. Walker (1992) and Lawton & Brown (1993) proposed that species often overlap in functional properties such that loss of any of them has negligible effect, and hence most species are redundant with respect to ecosystem services. On the other hand it was suggested that rich biodiversity provides insurance against changes in ecosystem processes that may impair service provision (Tilman 1996), so that diversity *per se* impart resistance and resilience to disturbances that disrupt ecosystem functions, namely ecosystem services (Christensen et al. 1996, MA 2005). Similarly, Ehrlich & Ehrlich (1981), comparing species to airplane rivets, suggested that each species loss contributes equally to the probability of large ecosystem changes. Further experimental approach (Naeem et al. 1994) supports the notion that differences among species in their responses to disturbances and environmental extremes make it unlikely that over time scales of decades to centuries there is much ecological redundancy in the species composition of an ecosystem (MA 2005).

The non-linearity of biodiversity-service provision function

Though the notion that service provision is positively related to the dimensions of biodiversity   (Mooney et al. 1995) is prevalent, this relations may be non-linear and a threshold in biodiversity dimensions needs to be crossed in order to significantly impair the provision of services (Ehrlich and Ehrlich 1981). This threshold hypothesis is consistent with observed shifts between different states of water quality linked with changes in lakes' fish diversity (Scheffer et al. 1993). The practical implication of the threshold hypothesis is that costs of ecological restoration rise steeply if ecosystems must be forced across a threshold to restore them. Yet the shapes of the curves, the locations of the thresholds (Schulze and Mooney 1993) and whether particular species are crucial in determining the location of the thresholds, are not known (Mooney et al. 1995).

Species loss and the precautionary principle

The discussion above implies that ascertaining the significance of any species in the provision of any ecosystem service will remain a challenge. Similarly unknown are the effect of removal of the "unimportant" species on the few species "important" in their direct contribution to services, and the reaction of an already altered biodiversity to further human-induced changes. Caution is therefore recommended in drawing conclusions about the ecosystem response to loss of a given species or of a reduced level of biodiversity (Mooney et al. 1995). To confront this state of the art, the CBD (Anonymous 1992) suggest that: "… *where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat"*. This is because biodiversity may be irreversibly lost by the time its economic and survival value is proved and valuated (Sagoff 1996).

It may therefore be prudent to apply the "precautionary principle" to policies for managing ecosystems. This principle implies a high value-driven judgment about the responsibility borne by the present generation toward future generations (Perrings 1991). Since current knowledge does not suffice, it is prudent to accept the option that an extinction threshold may exist, which if crossed can result in unacceptable degradation of ecosystem services. Accordingly, the precautionary principle implies that a justification for a loss of species by invoking redundancy is unacceptable. Since the precautionary principle entails a cost, decisions need to be made about how much it would have to be stretched or how much insurance different societies can afford to buy. This decisions-making process will be greatly assisted by better understanding of the relationship between biodiversity and ecosystem services. Until then it may be asserted that threats to biodiversity are indicative of threats to the provision of ecosystem services, including those related to water provision and regulation, and their balanced allocation to both people and "nature".

WATER-RELATED ECOSYSTEM SERVICES

Freshwater constitutes a good provided by ecosystems, so by definition freshwater constitutes a provisioning service. People intuitively associate the provision of freshwater with freshwater ecosystems (e.g. lakes, rivers, small streams, ponds, and wetlands). However, the ability of these ecosystems to provide water, which is the major non-living infrastructure of these ecosystems, much depends on terrestrial ecosystems, with regard to both quantity and quality of the water that make an ecosystem a freshwater one. Both terrestrial and freshwater ecosystems are involved in this provisioning service, yet they also provide other services, some of which are indirectly linked to water provision.

Water-related services of terrestrial ecosystems

Water-regulation services

For freshwater ecosystems to provide water, the water regulation service of terrestrial ecosystems is required. This service is mainly provided by the terrestrial ecosystems through their vegetation and its diversity. On the global scale this plant biodiversity regulates the single largest flux from the biosphere to atmosphere - the flux of water from the soil to the atmosphere (Schlesinger 1991), through the ecosystem function of evapotranspiration. This flux is counteracted by another provision of vegetation cover of terrestrial ecosystems, the shade that reduces soil surface evaporation. The vegetation cover of all the terrestrial ecosystems combined, through the physical structure and architecture of canopies and roots of all their different plant species combined, interact with the physical-chemical components of the ecosystem (soils, rocky ground surfaces), to regulates the rainfall flux once it reaches the ground surface and to determine the fate of raindrops: either to penetrate the soil directly and end up as soil moisture or as groundwater, or to generate runoff becoming floods, streams and rivers, reaching varying distances across the watershed, creating lakes, ponds and marshes or eventually returning freshwater to the ocean, which thus is denied from both people and “nature”.

Linked to their involvement in the global water cycle, terrestrial ecosystems, through their vegetation cover, regulate the global climate, through the ecosystem functions of photosynthesis and respiration that are involved in determining the gaseous composition of the atmosphere including the major greenhouse gas, carbon dioxide, and through the effect of vegetation cover on the earth’s reflection of solar radiation back to the atmosphere.

The water regulation services are of utmost significance in drylands (which combined comprise 41% of global land), since it is in these ecosystems that the service of primary productivity is limited by water availability. With no rivers that flow through deserts (Safriel 2007), or groundwater stored in drylands that can be extracted and used for irrigation, a significant proportion of the dryland populations would not have benefited from food provisioning services of many dryland ecosystems (Mooney et al. 1995, 1995a).

Water regulation and soil conservation tradeoffs

Terrestrial cultivated ecosystems may differ from other, “natural” terrestrial ecosystems or from the ecosystems that had been transformed to become cultivated ones, in regulating the water fluxes, controlled by their very divergent vegetation cover. In Israel, for example, Stanhill (1993) calculated that the potential water yield (volume of rain falling in a given year on a given surface area, minus volume of water returned to the atmosphere from the same area and year) of the natural, scrubland Mediterranean ecosystem receiving 400 to 800 mm of annual rainfall had been 1,590 km

/year received by this ecosystem once it has been transformed to a cultivated ecosystem. Thus, the water regulation service of the “natural” ecosystem was expressed in evaporating more soil water than the cultivated ecosystem replacing the “natural” one. This is therefore a case in which an ecosystem transformation by man improved the service of water regulation, thus increasing soil water contents to be used by

^{3}/year. This is lower than the current potential yield ^{3} 1,846 km agricultural crops. There are cases, however, in which the human transformation of non-forest to afforested ecosystem often results in reduced water conservation service, whereby the afforested ecosystem evapotranspire more soil water than the ecosystem it replaced (Sandstrom 1998).

It is likely, however, that the woody vegetation, whether "natural" or a result of ecosystem transformation, is more effective than the agricultural crop in providing a supporting service, that of soil conservation. This is so since Mediterranean scrubland ecosystems, for example, are known to conserve soil by protecting it from water and wind erosion, much better than cultivated ecosystems under the same soil and climatic conditions. Thus, the widespread ecosystem transformation in Israel, as in many other dryland agricultural countries, demonstrates a trade-off in ecosystem services. Namely, a promotion of the water conservation service has been attained at the cost of deterioration of the soil conservation service.

Water regulation and forage provision tradeoffs

In many arid (desert) dryland cyanobacteria, unicellular terrestrial algae, lichens and mosses jointly mould a hydrophobic soil crust. During rainstorms this crust generates surface runoff that is stored at the root zone of the patchily-distributed desert perennial shrubs (Boeken and Shachak 1994). Thus, rather than being thinly spread over the desert surface and evaporate, the water-regulation service, redistribute the water such that the water is protected from evaporation and sustains the shrubs during the long dry and hot season. This water-regulating service also minimizes flush floods and their associated damages, on-site (loss of topsoil) and off-site (clogging reservoirs with silt, and increasing sedimentation and turbidity that reduce water quality in freshwater ecosystem).

Also, the maintenance of the shrubs through the water-redistributing service makes them "islands of fertility" within the desert's apparently bare surface, through promoting growth of other plant species thus increasing the desert's primary productivity, which supports the service of forage provision and makes it a fertile rangeland. Overstocking, a prevailing practice mainly in common grazing grounds, leads not only to overgrazing, but to breakage of the crust through trampling. This damage to biodiversity (mostly of microorganisms) results in a cascading degradation of both water regulation, soil conservation, primary productivity and forage provisioning services. Thus, this overuses of the forage provisioning service leads to its own degradation, through an overall land degradation in desert drylands, termed “desertification”. A striking example is provided by the sandy arid ecosystems at the Egyptian-Israeli border (Fig. 2).

Insert Figure 2 here

Flood regulation service of terrestrial ecosystems

The flood regulation service of terrestrial ecosystem supports the water provisioning service of freshwater ecosystems, as well as of ground storages of freshwater. Flush floods erode soils that pollute freshwater ecosystems and man-made or managed water storages. Vegetation cover is instrumental in regulating the amounts of rainfall to be stored in the soil profile and in aquifers. When this vegetation is denied of the water it requires for its own maintenance and functioning, water provision for people is curtailed. This occurs when infrastructures and land are developed for urban or agricultural uses and interfere with surface and subsurface rainwater fluxes that feed soil moisture to be used by the natural vegetation in off-site areas.

Services provided by freshwater ecosystems

Services provided by wetlands

Freshwater ecosystems in general, and particularly in drylands, provide services to people living in surrounding and distant ecosystems. Wetlands – freshwater ecosystems either of a water table at or near the surface, or lands covered by shallow water of physical, chemical, and biological features reflecting recurrent or sustained inundation or saturation (Cowardin et al. 1979; NRC 1995) - provide the service of water purification through absorbing compounds harmful to functioning of the freshwater ecosystem itself, and for the people to whom the water is provisioned (Mooney et al. 1995). The slow rate of water movement in wetlands promotes the deposition of suspended material and provides time for biological mineralization of organic compounds and biodegradation of synthetic toxic chemicals (NRC 1992). The slow water movement supports the wetland submerged vegetation, which further slows water movement, adds deposited organic material to the bottom of the wetland thus reducing the depth of the wetland and contributing to its spatial expansion which further augments the water regulation, flood regulation and water provision services. This is through providing for water storage during floods and a promoting slow downstream release. The flood regulation service is thus expressed in lowering flood peaks and reducing their detrimental economic and environmental effects, including an off-site reduction of soil erosion and clogging of water reservoirs (NRC 1992).

Services provided by rivers and riparian ecosystems

Rivers and streams provide the service of water purification, which often replaces or augments wastewater treatment. The biodiversity instrumental in this service is that of freshwater microorganisms, whose great oxygen demand while processing the wastewater's organic load is satisfied by the oxidizing properties of the stream current (NRC 1992). Freshwater herbivores and predators regulate population sizes of these wastewater-treating species and thus their species diversity, required to treat the diversity of the compounds to be degraded or recycled. The vegetation on the banks of streams contributes to bank stabilization and when inundated - influences the rate of water flow. These two services of soil conservation and water regulation of the riparian ecosystem mould its physical characteristics of the stream, such as its channel's width and depth, that also affect the water purification service. When the pollution load, either qualitatively or quantitatively exceeds the capacity of the ecosystems in providing this service, it becomes "polluted" ecosystem, which requires rehabilitation efforts for restoring its services.

Services provided by lakes and man-made freshwater ecosystems

Rivers and lakes are engaged in the water provision, but lakes regulate the flow of outgoing rivers and function as water storages, often managed for added regulation of the water provision service. Lakes also provide the service of wastewater treatment - not as effectively as streams regarding organic load, but more effectively with respect to suspended solids. Finally, all freshwater ecosystems, often instrumental in water supplies or fisheries, are highly valued for their cultural services, especially where such ecosystems are scarce, like in drylands (Safriel and Adeel 2005, Safriel 2007).

Most man-made freshwater ecosystems like fishponds, wastewater treatment plants and constructed wetlands for wastewater treatment, recreational lakes and ponds, storm water management ponds, as well as canals and open-air reservoirs for water transport and storage, respectively are colonized by freshwater biodiversity, which includes aquatic microorganisms, plants, invertebrates, waterfowl and insectivorous bats (Carmel & Safriel 1998). These ecosystems provide the biodiversity-supporting service, and those constituting important wildlife habitats especially for migrating through or wintering birds (U.S. EPA 1993), provide cultural services, including recreation.

Other provision services of freshwater ecosystems

Freshwater ecosystems provide fibers such as reeds of wetlands, papyrus of marshes, trees of riparian ecosystems, food organisms such as fish and crustaceans, freshwater birds, and even microscopic unicellular algae (e.g. *Spirulina* in Lake Texcoco, Mexico and Lake Chad, Chad). Many species of freshwater ecosystem have been domesticated, including waterfowl (ducks, geese) and fish (e.g. carps, tilapia and others). Nearly all of these species cultivated in man-made freshwater ecosystems have progenitors and wild relatives in the “natural” freshwater ecosystems. While the domesticated species are either endangered due to the erosion of their genetic variability or suffer from reduced genetic potential as compared with their progenitors, the progenitors and the wild relatives not only maintain variability but also continue to evolve in “natural” ecosystems in response to changing conditions. Hence these ecosystems constitute a repository of transferable genetic variability (“biogenetic resources”) that can counteract the genetic erosion of the cultivated species and be instrumental in developing new varieties.

THE VALUATION OF ECOSYSTEM SERVICES

Unlike the provisioning services most of which produce or deliver goods of monetary value in the marketplace, all other ecosystem services are rarely bought or sold (Christensen et al. 1996) and their valuation is a challenge. Defining ecosystem services as flows of materials, energy, and information from natural capital stocks which combine with manufactured and human capital services to produce human capital, Costanza et al. (1997) have attempted to value ecosystem services by estimating the "willingness to pay" for them. Although this pioneering work attracted criticism (e.g. Perrings 2006) it draws attention to the significance of water-related services, relative to that of other services (Costanza et al. 1977). The estimated value of 17 ecosystem services provided by 16 ecosystem types combined, was estimated at an average of US$33 trillion per year, which is nearly twice the global gross national product of US$18 trillion per year). The highest value, more than half of the total value of all ecosystem services combined is that of nutrient cycling, estimated $17 trillion per year. All other services are of a much lower values, expressed in percentages of the total value in Fig. 3. It is evident that the water-related regulating services are more valuable that other regulating services, that the provisioning services of food and fiber are more valuable than that of water provisioning, and that all cultural services combined (provided by both freshwater and terrestrial ecosystems) have the second highest value after nutrient cycling (Fig. 3). Despite their small global area, aquatic ecosystems were found to be very valuable. Coastal estuaries are the most valuable (US$23,000ha $^{-1}$ yr $^{-1}$). More striking is the comparison of the value of the global freshwater ecosystems as compared to all other terrestrial ecosystems (Table 1). Whereas all freshwater ecosystems comprise only 2.4% of all non-marine ecosystems (terrestrial and freshwater combined), the value of their services is 40% of the value of all non-marine ecosystems. And the average annual value of services per hectare of a freshwater ecosystem is 16.8 higher than that of the hectare of non-marine ecosystem.

In spite of shortcomings of this valuation exercise, its presentation here not only draws attention to the danger of ignoring or undervaluing services of ecosystem just because they are largely outside the market, but also to the rather disproportionate value of water-related ecosystem services, and the freshwater ecosystems that generate many of them. Furthermore, since the natural capital that provides the services is projected to become scarcer in the future, the value of the services will increase, to the point that when irreversible thresholds will be crossed for irreplaceable ecosystem services, their value may rise to infinity (Costanza et al. (1997).

Insert Fig. 3 and Table 1 here

THE CONSEQUENCES TO “NATURE” AND PEOPLE OF WATER RESOURCE DEVELOPMENT

Water resource development, biodiversity and services

“Water resource development” means intensification of water-related ecosystem services, especially the water provisioning one. This intensification is attained through “development”, which entails management of freshwater ecosystems, whether they are “natural” or not. This management that may include, for example, increasing storage capacity by damming, or increasing water output by enlarging outlets, pumping and constructing water conveyance structures. The provisioned water is thus transported to other ecosystems and through irrigation with this water their transformation to cultivated ecosystems is accomplished, in which the services of primary productivity and food provisioning are intensified. Indeed, water resource development has driven a steady increase in the extent of global irrigated agricultural land (from ca 140, to 250, to 170 and to 270 million hectares in 1961, 1994, 1970 and 2000, respectively, Brown et al. 1997, UNEP 2002). The activities involved in such water resource development constitute the “direct drivers” of change of ecosystem services (Fig. 4), often causing unintended detrimental changes in other ecosystem services, meaning a trade-off in the provision of ecosystem services.

The direct drivers of change are themselves driven by indirect drivers of changes of ecosystems and their services, which are not biophysical but demographic, social and policy ones. These are motivated by aspirations of increasing human well-being, but often achieve the opposite. When the latter outcome of the development becomes evident in a reduced human well-being, this development is qualified as non-sustainable one. People may then react to their reduced well-being in taking actions that constitute a change in the indirect drivers of ecosystem change (Fig. 4).

Insert Figure 4 here

Water resource development promotes not only agricultural but also urban expansion, mainly in drylands. These nearly always detrimentally affected biodiversity, and since biodiversity is instrumental in the provision of ecosystem services, it is the damage to biodiversity that makes the water resource development and its consequent rural and urban development, non-sustainable.

The damage to biodiversity occurs first within the ecosystems transformed to urban and cultivated ones and results in a degradation of some ecosystem services. For the farmer, for example, the loss of some of the services provided by the ecosystem prior to its transformation to his newly created farmland is not an adversity, since his expectation from the farmland only pertains to the biological productivity service, with which he is likely to be fully satisfied. But the transformation-induced damage to biodiversity permeates off the transformed plot to various distances and at larger spatial scales and impinges on the remaining, non-transformed "natural" ecosystems. This is since the survival of a species depends on its population size and the smaller the population the risks of its local extinction increase. Since population size is directly related to the size of the species' ecosystem area (which includes the habitat of the species), the agricultural (or urban) transformation reduces the non-transformed area of the species' ecosystem and habitat, thus leading to its population decline, which may be detrimental to the provision of services in which this species is involved. Furthermore, when population is reduced to a species-specific threshold the species may become locally extinct (NRC 1995a). Similarly, as the reduced area of an ecosystem reaches an ecosystem-specific threshold, the number of its species declines (Soulé 1986), and hence overall service degradation may occur. This population decline of species and even their local extinction and the overall reduction in number of species translates into a gradual spatio-temporal deterioration is service provision of ecosystems that have not been transformed.

An added adversity to species' persistence is the fragmentation of the "natural" ecosystem associated with development. Even if ecosystem transformation reduces the overall habitat size of a species by only a small fraction, but it is done in non-contiguous patches of development that fragment the formerly contiguous non-transformed, "natural" ecosystem, then the population in each fragment is bound to be small and at risk, including the risk that all the fragmented populations will sequentially become extinct.

Once the transformation to cultivated systems has taken place and cultivation is in place, a third source of biodiversity decline outside the agriculturally-transformed ecosystem emerges. The increasing use of pesticides and fertilizers, especially when applied from the air disperse into adjacent and distant non-transformed ecosystems. Insecticides and herbicides are often concentrated at top levels of the biodiversity food chain, sometimes reaching lethal concentrations in top predators. These top-down effects on "natural", non-transformed ecosystems may be highly detrimental to their provision of services. Pesticides are also transported by runoff, and thus affect freshwater ecosystems and contaminate ground water. Fertilizers too are applied in large quantities, often in the irrigation water. Fertilizers reach aquatic ecosystems, where they can cause eutrophication, and they too contaminate ground water. Also, harmful trace elements, especially selenium, are often abundant in agricultural drainage water (Anonymous, 1989) and these can be further concentrated in the food web and damage biodiversity. Thus, water drawn from lakes, rivers, and aquifers for developing irrigated agriculture is returned to aquatic ecosystems in a contaminated state, what reduces biodiversity, with a resulting degradation of ecosystem services, including water-related ones.

To conclude, on the local scale of the individual farm the water resource development that drove agricultural development is perceived as successful for some time. On a greater spatial scale, and over a longer time period, the reduced biodiversity resulting in degraded service provision away from the farm, will be felt in a large area, and including both the transformed and the non-transformed ecosystems.

An example to the detrimental effect of water resource development on agriculture is the development of groundwater-based irrigation, which often drives huge transformation from "natural" ecosystems with their species- and structurally-diverse vegetation cover, to cultivated ecosystems with a single-species seasonal vegetation cover. Since the recharge of groundwater depends on the water regulation service of the non-transformed ecosystems and their vegetation cover, the reduction in the spatial extent of this cover reduces overall recharge, and the amount of irrigation water available for the cultivated ecosystems. The magnitude of this reduced recharge depends on the geomorphological properties of the transformed ecosystems, their geographical placement with respect to regional aquifers, and the properties of their vegetation biodiversity. It also depends on the agro-technological practices and type of crops in the transformed ecosystems. Furthermore, large-scale transformation of "natural" ecosystems by cultivated systems results in reduced structural and landscape diversity, which impairs the resilience to episodic high rainfall events. The large-scale removal of perennial vegetation and its replacement by agricultural crops also causes regional changes in albedo, evaporation, cloud formation and rainfall distribution. When landscape structural diversity around freshwater ecosystems is reduced, this leads to changes in their chemical, physical and biotic features that may be irreversible (Mooney et al. 1995a), and affect the prospects of continued withdrawal of this water for irrigating cultivated ecosystems.

Services not directly related to water are often compromised by water resource development aimed at agricultural and/or urban expansion. One such service is that of disease regulation (not control!). When water is diverted from a local river such that stream flow is significantly reduced, dramatic changes in biodiversity composition and hence in service provision, including that of disease regulation may occur. The reduced flow may create favorable conditions for mosquitoes, many species of which are vectors of human diseases. This may be an example of a unexpected outcome detrimental to human well-being brought about by water resource development at a small spatial scale. But there are also examples of large-scale water resource development projects of severe repercussions on a grand scale, which compromised a whole suite of ecosystem services. Lake Chad and the Aral Sea disasters are such salient examples, whereas the sustainability of Lake Nasser construction and the Sea of Galilee management for promoting agricultural and rural development is still waiting for time to pronounce its verdict. To conclude, water resource development enables agricultural expansion, which may turn out non-sustainable, since the development reduced rather than promoted the ecosystem services of water provision, and this through direct and indirect damage to biodiversity.

Water resource development and freshwater ecosystems

Lakes are often managed as operational storage of water, and wetlands drained in order to reduce evaporative loss and expand agricultural land. The effects of draining wetlands cascade to adjacent and remote ecosystems. The Rift Valley's Jordan River Basin management serves as an example of how detrimental effects of water management can cascade to adjacent and remote freshwater and other ecosystems. The Hula, a small valley at the head of the watershed, with a large swamp draining into a small lake, was completely drained in the 50s of the 20th century and replaced by croplands, save a small section on which a nature reserve was reconstructed. More than an ecosystem transformation, the Hula drainage was an ecosystem construction, whereby the service of primary productivity formerly delivered by freshwater organisms was now to be provided in an intensified rate by a terrestrial ecosystem. No wonder that exposed wetland's peat bottom to air intensified not the service of primary productivity but the service of nutrient cycling. Namely, the intensified decomposition of the surface, rich in organic matter that had been saved from decomposition due to mostly anaerobic conditions prior to drainage, lead to fast mineralization and consequent generation and accumulation of nitrates. Winter flooding led to the washout of nitrates through the Jordan River to Lake Kinneret (Sea of Galilee), , located downstream in the watershed, thus risking the initiation of processes leading to the lake's eutrophication and thus compromising the water quality of the major water reservoir of Israel (NRC 1999). Also, the flood regulation and water purification services of the wetland were lost, further risking water quality of the Kinneret. Furthermore, decomposition of the peat and peat fires caused surface subsidence, leading to winter flooding of sections of the drained wetland, which compromised cultivation, the very objective of the draining project.

When investments in water management put down the fire, prevented further subsidence and provided for cultivation, the mono-cultural cropping on large, contiguous areas triggered vole plagues. Massive rodent control with toxic bait made the intoxicated voles an easy prey for local and migratory raptors, causing secondary poisoning mortalities of the birds, some of which belonging to endangered species. Eventually the area where the surface sunk most was transformed into a recreational lake serving as a waterfowl refuge and attracting wildlife. Ecotourism attracted by this development and promotion of the restored wetland’s cultural services compensates the farmers for not attaining the fully aspired income from agriculture. As to the Kinneret, pollution from the drained swamp was averted, but the intensification of its service of water provision and regulation reduced the flow of the Jordan River into the Dead Sea, a landlocked lake at the end of the watershed. Beside changes in provision of fish and biodiversity of the Kinneret and the Jordan River, respectively, the Dead Sea level retreated, and the stability of its exposed coasts as well as sections adjacent to them was dramatically reduced, through the emergence of potholes that pose life-threatening dangers to people and transportation.

These large-scale water resource development projects, however, proved insufficient for satisfying the needs of the increasing population of Israel, and water shortages are have to be responded by large scale seawater desalination. In retrospect, if the understanding of the role as well as the limitations of ecosystem services in water provision and regulation had prevailed two generations ago, the contemporaneous history would have been different. The whole Jordan Valley watershed ecosystem could have remained intact with the full diversity of its services functional, while water demands that could not be met by the local ecosystems would have been satisfied with freshwater generated by wastewater treatment and seawater desalination projects that could have been in place much earlier.

In many drylands the rainy season generates ponds that completely dry out during the dry season. Some of these ponds have been created by ancient damming and quarrying, and were used for generations to water livestock in early summer. Such ponds harbor unique species, adapted to the ephemeral conditions, usually by having an amphibian lifestyle or leaving dormant propagules in the soil of the dried-up bottoms of the ponds. When wet, the ponds attract wildlife that comes to drink or to prey on other animals. In many dryland countries these ponds are drained and transformed to cultivated ecosystems. Other ponds become sinks for wastewater of high toxicity or high organic load, or are intentionally drained or sprayed to control mosquitoes. The biodiversity of ephemeral pond ecosystems has been reduced by this spraying, and by their spatial rarity, which prevents migration between them. Implicating pond ecosystems as a mosquito threat is flawed since the ponds' natural predators—tadpoles and predatory insects, control mosquitoes and maintain their populations at low levels, what constitutes the disease regulation service of these ecosystems. The use of pesticides to control mosquitoes aggravates the situation: the biodiversity component that provide a biological control service are destroyed, and the mosquitoes evolve resistance to the pesticides. Beside water provision (for livestock) and disease regulation these ecosystems also provide cultural services - recreational, educational, and scientific, given the unique nature of their biodiversity and their dynamic ecology.

Water resource development and terrestrial ecosystems

Spring water is often pumped and impounded within a sealed concrete construction, to prevent evaporation and to protect from vandalism. These practices affect both the riparian biodiversity along the stream, mostly of plants, and the freshwater biodiversity of the ponds and streams themselves. But the effect of drying streams and obstructing access to ponds also cascades to the terrestrial ecosystems adjacent to the springs and streams, and ultimately even farther.

Lowering the water table through pumping aquifers may pose risks to terrestrial biodiversity, and hence to services of terrestrial ecosystems, some of which related to water regulation. Such pumping detrimentally affects dryland ecosystems dominated by trees that tap relatively high water table (Ward and Rohner 1997) or reduce the discharge of springs, thus curtailing the flow of streams or transforming permanent spring pools into ephemeral ones. Another common practice, especially in drylands, is damming runoff courses and constructing open-air reservoirs.

The floodwater is stored in the reservoirs and used for irrigation or to recharge aquifers. Though the objective of dams is to minimize runoff to the ocean or to land-locked saline lakes or marshes, floodwater contributes to the productivity of the terrestrial ecosystems along their courses, through a combination vertical infiltration concomitant with lateral redistribution. Therefore, unlike other practices, which have a strong local effect (mostly on lakes, marshes and riparian biodiversity), and a smaller regional effect on species of terrestrial ecosystems, damming has a regional, whole-watershed effect, mostly on terrestrial biodiversity. The closer the dam is to the water divide, the larger the area of watershed affected. Thus, dams and reservoirs promote agriculture, but also adversely affect the watersheds' downstream ecosystems. In hyperarid dryland watersheds, the channel is the only landscape component with terrestrial perennial vegetation. Installing dams in these drylands has a stronger effect on biodiversity than building them in drylands of lower aridity (arid, semi-arid and dry sub-humid drylands). Damming also reduces the subsurface runoff in the channel, which lasts longer than the surface runoff and is critical for the persistence of the channel vegetation and its animal biodiversity.

Finally, reservoirs enrich the desert with open water bodies that may dramatically affect the behavior, population dynamics, and structure of the desert's terrestrial animal communities and hence desert ecosystem service. These effects are not yet well understood, but it is evident that by reducing flows in channels, damming reduces severe erosion and loss of organisms when preventing flash floods, but also reduces the leaching of salts and the deposition of nutrient-rich soil when arresting moderate floods.

Water resource development and freshwater biodiversity

Because probability of extinction increases with reduced ecosystem size and increase in isolation, and freshwater ecosystems are scarce and therefore isolated from each other, and often they are relatively small especially in drylands, freshwater ecosystems are exposed to high risks of biodiversity losses, resulting in service degradation. The Israeli Hula wetland and its drainage project, discussed in a previous section of this paper is a good example.

Prior to drainage 585 freshwater animal species (excluding unicellular and parasitic species), were recorded in this wetland, of which 19 were represented by their peripheral populations, occurring at the southern or northern limit of their species' global geographical distribution, and 12 were global endemics, found only in the Hula (Dimentmann et al. 1992). In-spite of reconstructing a nature reserve shortly after drainage, 119 (20%) of the species including 11 of the 19 species represented by peripheral populations, and 7 of the 12 endemics, disappeared. The loss of the seven endemic species, among them a frog and a fish, constituted global extinction. Furthermore, 36 of the species lost to the Hula, have not been recorded anywhere else in Israel since the drainage. Of the 36 bird species breeding prior to drainage, 10 ceased to breed but 5 of them were replaced by species that had not breed there prior to drainage. Thus, the drainage of a dryland wetland which is relatively small in global terms, resulted in a local loss of 119 species (plus 10 birds species that ceased to breed there), national loss of 36 species, and global loss of 7 animal species. On the other hand, 212 aquatic animal species new to the Hula have been recorded in the Hula region only after the drainage. Some of these might have existed prior to the drainage but escaped attention. Others are new colonizers, indicative of the changes in habitat extent and diversity, and in the quality of the water, following the drainage and subsequent reconstruction efforts. It is not know whether or not the ca 200 new species compensate for the ca 120 lost, with respect to the provision of currently required ecosystem services.

Furthermore, the geographic placement of the Hula brought together species whose center of distribution and origin is north (Europe), west (Mediterranean Basin), east (Iraq, Iran) and south (Egypt, tropical Africa). Though most of the species also exist elsewhere, their combination, hence their interactions exist nowhere else, and could have been resulted in unique quality of ecosystem services. Thus the drainage brought about not just loss of individual species, but of exceptional freshwater biodiversity and services typical to climatic transition areas.

Also, dramatic natural phenomena, such as the upstream spawning migration into the inland Dishon stream, of Lake Hula's three cyprinid fish, are forever lost, though the species themselves have not gone extinct. Finally, due to the Hula's location on the route of cross-desert bird migration, where they refuel prior and following the Sahara crossing, its drainage may have detrimental effects on service provision of both European and African ecosystems, since the birds that used to stage in the Hula have constituted a significant biodiversity component, in summer (European ecosystems) and in winter (African ecosystems).

The loss of biodiversity due to the Hula drainage is only a part of biodiversity losses in a dryland country like Israel in which water is scarce but its use is intensive. Thus, though by year 2008 Israel as a whole has lost only three vertebrate, five invertebrate and one fern species from its freshwater and riparian biota, many more species are at high risk. Using IUCN categories of species endangerment, it is evident that among the 491 mammal, reptile, amphibian fish, fern, and monocotyledon plants (excluding grass) species of Israel only 14 % of non-freshwater species but 35 % of freshwater species are at risk. Nathan et al. (1996) showed that, although waterfowl and raptors consist of only one-third of the regularly breeding birds of Israel, all but one of the 14 extinct bird species of Israel were waterfowl (7 species) or raptors (6 species, 4 of which were mostly wetland or riparian). These data suggest that further reduction in the size or water quality of freshwater ecosystems of Israel could cause the extirpation of more than 35 percent of their vertebrate and plant species (and probably a high number of invertebrate species). Such a loss is likely to have a significant effect on the ecosystem service to be then provided to people there.

The significance of freshwater biodiversity losses

It may be interesting to speculate, in retrospect, how people would have benefited from ecosystems like the Hula Lake and wetland, if they would not have been drained and their biodiversity would have remained intact. The Hula diverse ecosystem would have been instrumental in flood regulation and water purification, in food provisioning (fisheries), but mainly in the provision of cultural services, that could have been a direct source of income when the use of such services is translated to ecotourism and recreation. Given also the emerging issue of global climate change, it would have been also instrumental in carbon sequestration and engaged in the global carbon trading. A contentious problem could have been that of the service of disease regulation. It should be noted that the incentive to plan the Hula drainage project was the plight of Malaria. Its effect on its indigenous population that subsisted on the provision services of this ecosystem has not been carefully documented, but its effect the immigrant European population that colonized the region in the late 19th and early 20th century was devastating. However, during the period between initiating planning and the “ground breaking” of the project, the Hula malaria has been fully eradicated, never to return even when small parts of the ecosystem were restored. Thus, it was DDT, netting of housing and isolation and treatment of infected people applied simultaneously and combined, that eradicated both the parasites and their vectors. This suggests that in the case of malaria the disease regulation of this freshwater ecosystem did not suffice, though no intervention in the functioning of this ecosystem was required for attaining the required control.

Desertification and global climate change – effects on ecosystem services

Effects of desertification and climate change on ecosystems

Transformation of “natural” ecosystems to cultivated ones occurs mostly in drylands, since most good cultivable land, which is outside the drylands, is already cultivated (Safriel and Adeel 2008). Dryland development is often transformation of ecosystems used as rangeland to cultivated ecosystems. The removal of large tracts of indigenous vegetation to make room for cropping reduces biodiversity, hence the quality of the remaining range, encourages overgrazing what compromises the service of soil conservation, thus leading to topsoil erosion. As to the transformed ecosystems, the dependence of dryland cropping on irrigation under the high evaporation of drylands encourages salinization, whereby the quantities of water required to leach the salts are prohibitively large and the accumulated salinity reaches a threshold value at which the cultivated ecosystem can no longer provide the service of primary productivity and food provisioning, and is abandoned. It can then be colonized by halophyte vegetation, rather than re-colonized by the forage biodiversity of the non-transformed rangeland ecosystem. Thus, either due to loss of topsoil or due to salinization or both, land degradation expressed in erosion, salinization and reduced service provision, may reach the point of irreversibility, which also means that its biodiversity may never be restored unless heavy investments in restoration are made. This extent of land degradation is labeled "desertification" that currently affects some 10-20% of the drylans, much it driven by water resource development, itself indirectly driven by demographic and policy drivers (Adeel et al. 2005). Although desertification is often triggered by a large external disturbance (Puigdefabregas 1995), its underlying causes begin years or even decades before crises manifest themselves (e.g., the Dust Bowl in the United States in the 1930s and the Sahel crisis in the 1970s).

Man-induced climate change is expressed in elevated temperatures associated with increased evaporation (and transpiration), and in drylands - reduced precipitation (Meehl and Stocker 2007), reduce soil moisture and a decrease in water resources (IPCC 2007). Climate change can be mitigated by reducing emissions, promoting sinks (processes which remove carbon dioxide from the atmosphere) and generating or maintaining "reserves" (storages of organic matter that is relatively secured from being oxidized to atmospheric carbon dioxide). It is the climate regulation service of all global ecosystems combined that regulates the concentration of greenhouse gases in the atmosphere, through the supporting services of primary productivity and nutrient cycling within the global ecosystems, in the provision of which the biodiversity of plants and micro-organisms is intimately involved. Global plant life generates the sink service and the global biota, of which plants constitute the largest fraction by mass, provides the service of maintaining the carbon reserve. Since the service of climate regulation is provided by vegetation, much of which is limited by water, a reduced allocation of water to “nature” would exacerbate global warming.

Water resource development, climate change, biodiversity, and desertification linkages

The causes for desertification are the same as those causing the degradation of the climate regulation service of ecosystems, which fail to provide the sink function and to maintain the global carbon reserve (Safriel and Adeel 2005, 2008). Namely, deforestation and removal of other types of vegetation cover contribute to global warming and climate change on the global scale, while the same processes but occurring just in the drylands result in desertification. This large-scale vegetation removal, either globally and especially in the drylands, is a result of ecosystem transformation, from “natural” ecosystems of a sustainable provision of a diversity of ecosystem services, to cultivated ecosystems that promote primary productivity at the expense of other services. Because many crops are annual, and when harvested their organic matter is not sequestered but removed from the ecosystem, to be eventually oxidized to become atmospheric carbon dioxide, and because there is often a time lapse between harvesting one crop and growing the next during which the bare soil is exposed to wind erosion or water erosion, reducing fertility and removing organic material from the ecosystem, cultivated systems do not provide an effective soil conservation and climate regulation as the ecosystems they replaced. Furthermore, when become desertified these cultivated ecosystems will cease to provide a sink service and their service of maintaining carbon reserves will be impaired. Thus the intensification of water provision in the drylands is linked to desertification, and desertification, loss of biodiversity and climate change are then mutually reinforcing and exacerbating each other (Fig. 5). To break these vicious circles balancing water for people and "nature" would not suffice, though prudence with water resource development is required.

Insert figure 5 here

Climate change related ecosystem service of climatic transition zone

One option for mitigating the detrimental effects of climate change on biodiversity and hence on service provision is to refrain from water resource development leading to ecosystem transformation in climatic transition zones. This is because these areas may provide the ecosystem service of mitigating detrimental effects of climate change on ecosystems already affected by climate change. This service is currently expressed in the maintenance of unique biodiversity, namely plant species with high within-species, genetic diversity. These species have their core populations away from the transition areas but distribution tapers in climatic transition belt, inhabited by the peripheral populations of these species. In these areas high between-year climatic variability prevails, such that in some years the climate there resembles that of one side of the transition, and in others - the climate of the other side. This exposure to fluctuating climates selected for the maintenance of high genetic variability within peripheral populations of species (Kark et al. 1998, 2008). Due to this genetic diversity, these populations are likely to persist in the climatic transition zone even under projected conditions of global climate change, whereas the populations of the same species inhabiting the core distribution areas and not endowed with such diversity will go extinct. This will cause an overall impaired biodiversity of the ecosystems away from the climatic transition zone, and hence put many ecosystem services at risk. The peripheral populations of these species, inhabiting the climatic transition zone are likely to survive the climatic change, and hence can then be transported to ecosystems damaged by global climate change, and thus become instrumental in restoring the lost services of these ecosystems (Safriel et al. 1994). Thus, ecosystems of climatic transitions zones provide the service of supporting a biodiversity to be used for rehabilitation of other ecosystems, whose services would be impaired by the projected global climate change.

However, this genetic biodiversity supported by ecosystems of the climatic transition zones, may be lost if population pressures in the climatic transition zones bring about water resource development that encourages the transformation of "natural" ecosystems there to cultivated ones, which surely will not provide the service of supporting these biogenetic resources. It is especially important to conserve the biodiversity of the desert/non-desert climatic transition zone, since water resource development there can end up with desertification, under which these peripheral populations would surely not survive.

BALANCING WATER FOR PEOPLE AND FOR NATURE

Water needs of nature

The previous sections developed the notion that the issue at stake is not how much water to allocate for "nature", at the expense of water for people, so that "nature" is sustainably maintained. Rather, the issue is how much water can be allocated for driving the current trends of global population and economic growth without degrading and reducing ecosystem services to the point that these cease to support these trends, thus bringing about a mutual collapse of both "people" and "nature". Surely, "nature", or ecosystems, irrespective of their degree of naturalness, require water for maintaining their biodiversity that is instrumental in the provision of their services. Also, people require water for maintaining themselves and society, and this water is provided by functioning ecosystems. The point to be made is that even though ecosystems can continue to serve people with less water that is available for ecosystem functions today, their services will nevertheless be degraded if the water not used by ecosystems will be used to support further population and economic growth. This is because inasmuch as water is critical for ecosystem health, their biodiversity needs space and relief from pollution, even much more than it needs water. Nevertheless, in the following section of this paper mostly water issues are addressed, and means to maintain and secure water-related ecosystem services are proposed.

Restoration of freshwater ecosystems

Water allocation to natural ecosystems

Little knowledge of the quantity and quality of water required by "natural" ecosystems for maintaining their biodiversity and providing their services exists. Where there are legal allocations of water "for nature" these are determined as compromises rather than based on the knowledge of ecosystem's needs, whatever this "need" means or defined. In Israel for example, between 0.2 to 2.0 percent of mean annual total renewable water is allocated to protected ecosystems (NRC 1999), though this amount is likely to be insufficient for securing freshwater and riparian ecosystems and their services. A prevailing notion is that all effluents need to be removed from freshwater ecosystems. But the grim prospects of severe water shortages suggests that many rivers will dry up if the discharge of high-quality effluents back to them is not practiced. The notion of using wastewater to help support biodiversity is based also on the belief that many ecosystems can "serve themselves" by processing wastewater to a level that supports their "needs".

Wastewater for rehabilitation of freshwater ecosystem

Reuse of treated wastewater for cultivated ecosystem is recently emerging, especially in dryland countries. In Israel, for example, self-purification values in several sections along the course of the Yarkon River (measured as pollutant concentration at the down-river end of a section minus its concentration at the up-river start of the section, divided by passage time through the section), ranged 0.1 to 0.5, 0.5 to 0.6 and 0.2 microgram/liter/second, for biological oxygen demand, chemical oxygen demand and ammonium concentration, respectively. These are very high values of purification capacity per unit time, typical of an eastern Mediterranean climate (Rahamimov 1996). To increase the self-purification potential of the Yarkon, small dams have been constructed and the impounded stream above them is artificially oxygenated. A National River Administration coordinates the restoration of river ecosystems, including this use of wastewater. Though the motivation is promoting the cultural services, e.g. recreation, the rehabilitated rivers support biodiversity and provide ecosystem services better than prior to their rehabilitation. Freshwater is allocated to in these rehabilitation project, and it is not water lost agriculture, because most of it is impounded at the lower reaches of the rivers, and the fraction lost by seepage recharges aquifers.

Development planning guided by ecological considerations

When a new development project is designed, it is not enough just to evaluate the availability of water for supporting this project. Rather, the ecosystems that are expected to provide this water need to be identified. Furthermore, the dependence of water provision and regulation services of these ecosystems on other ecosystems need to be evaluated too. Finally, the effect of the projected utilization of these water-related services by the planned development, on the biodiversity of the relevant ecosystems, should be assessed, as well as the services that will be compromised due to the exploitation of the water-related services.

Following the above evaluations, the areas in which the development is to be set, and hence would constitute a transformation of another, “natural” or other ecosystem, needs to be evaluated too. For example, it is necessary to explore how much would the flow of services from the relevant ecosystems be diminished (or augmented) if the next hectare of that ecosystem is transformed, though the assessment of this marginal value is complex (Bawa & Gadgil 1997). Another option is to estimate which is greater, the economic benefit of a particular development project or the benefits provided by the ecosystem that would be transformed (Daily et al. 1997). Indeed, evaluation of human impact on ecosystems (Soberon et al 1999, Wackernagel et al 1999) and of ecosystem services (Costanza et al 1997) were attempted, yet the required knowledge for doing that for local and regional planning purposes are insufficient. Since demand for such evaluations grows faster than the pace of the required research existing knowledge can be used while knowledge is being produced.

Valuation of terrestrial ecosystems in the planning process

Such an evaluation needs to explore (a) the state and trends of the ecosystem services provided by the ecosystem; (b) the state and trends of the ecosystem's biodiversity, and the role of its components in the provision of the different services; (c) the susceptibility of the ecosystem to damage - its ability to absorb anthropogenic disturbances without loss in its ecosystem services (resistance), along with its potential for rehabilitation following disturbance (resilience; Safriel 1987). Each of these criteria can be quantified by applying current knowledge, paradigms, or prevailing notions, as follows.

Regarding regulation services, it is customarily assumed that the larger the number of vegetation layers, the greater is the infiltration potential and the smaller the risk of soil erosion and intense surface runoff; and the larger the number of species, the greater the number of vegetation layers. Conservationists, however, always presented with choices to be made with respect to conservation of individual species, and thus try to rank ecosystems' values by the prevalence of high ranking species within them. With regard to potential economic value, i.e. mainly but not only species involved in the provisioning services, the ranking can be as follows: (1) progenitors of cultivated species; (2) wild relatives of cultivated species; (3) non-cultivated species currently collected for nutritional, medicinal, ornamental, aromatic, biofuels, and industrial purposes; (4) forage or fishery species; (5) species represented by peripheral populations, hence with high genetic diversity; (6) species identified by IUCN criteria under categories of vulnerable and rare (including species whose economic significance has not yet been explored, but whose extinction would prevent the elucidation of value, if it exists); (7) species instrumental in the provision of cultural services (which often translate to economic benefits); (8) species of scientific interest (which also have economic value, including value generated through scientific discoveries); and (9) species that provide or manipulate habitats for other species (Jones et al. 1994). An ecosystem can be scored by the number of its species in each of the above categories, multiplied by the rank of the category.

Because freshwater ecosystems also affect biodiversity of adjacent terrestrial ecosystems, by provisioning water for terrestrial vegetation, and water and food for terrestrial animals, and therefore terrestrial ecosystems in proximity to freshwater ecosystems should be ranked higher than other terrestrial ecosystems. The evaluation of freshwater ecosystems needs to take into account that they are relatively scarce and small in size especially in dryland, hence their biodiversity is inherently at risk. Therefore, for comparing the value of a freshwater and a terrestrial ecosystem, the scores for each of the nine criteria above should be higher in the former than in the latter.

Another criterion for ecosystem ranking in the planning process is their disposition to rehabilitation of their biodiversity and ecosystem services following disturbance and ecosystem transformation. These would be aster when the ecosystem is close to sources of immigrants. These sources are other areas with protected biodiversity, so their significance increases as they are closer to the disturbed or transformed area. The penetrability of the surrounding areas for dispersing units interacts with their distance: the greater the penetrability of the areas, the farther the dispersing units can travel. For example, a surrounding agricultural area is more penetrable than a surrounding urban region. For ranking freshwater ecosystem with regard to their rehabilitation potential their distance from polluting sources and the existence of corridors, such as streams that connect isolated freshwater ecosystems should score them higher than terrestrial ecosystem with respect to their value and conservation needs.

To conclude, the most valuable ecosystem for a reliable provision of ecosystem services is one with highest biodiversity, with a large component of species with a potential economic significance and of known contribution to the provision of ecosystem service, with a large contiguous size, and connected by corridors to other similar ecosystems. Using the above rather generic guidelines, it is feasible to evaluate ecosystems with regard to their performance as water-related service providers..

Such a procedure would be the first stage in trying to strike a balance between the level of human well-being to be aspired, and the ability of ecosystems and their biodiversity to provide for it.

Recommendations

This paper equates "nature" with its role in maintaining a sustained flow of ecosystem services, including water-related ones, whose importance to the functioning of the ecosystems themselves, as well as to human well-being, increases with climatic aridity, on both spatial and temporal scales. Thus, balancing water for nature and people simply means maintaining "nature" as just defined. However, there is a gradation of "naturalness" of ecosystems, with absolutely natural ones nearly inexistent, yet all the rest, even those most aggressively transformed by man, do provide ecosystem services. The problem is to recognize, identify, measure and evaluate the quality and quantity of services required by people as against the potential of the different ecosystems to provide them, including their involvement in water-related services – the main driver of human development especially in drylands. Unfortunately, much of the knowledge required for these undertakings is not yet available.

The following sections highlight the scientific knowledge needed to be developed for better understanding the relationships among ecosystem services, ecosystem structure and function, and biodiversity, and also the information required for assessing the balances and tradeoffs in development that always comprises ecosystem transformation and service tradeoffs. The recommendations are succeeded by operational recommendation for planning development projects given the current, existing knowledge.

Research recommendations

1. Identify and quantify the services provided by each ecosystem type. Identify the optimal and minimal water (quantity and quality, in time and space) and land (size and spatial pattern) required by each of these ecosystems for securing the sustainability the provision of their services, in different mixes that can be determined by development needs and trends.

2. Determine which of the ecosystem types within the landscape proposed for development play landscape-relevant keystone roles, and explore means to maintain ecosystem processes, and hence biodiversity at the landscape and regional scale, in balance with designed development projects.

3. Identify species that are endangered or at risk of becoming endangered, assess the contribution of each to water-related as well as other ecosystem services, identify the causes for the endangerment of these species, and explore means to reduce the risks.

4. Compare local water losses from evapotranspiration in different ecosystems under the different management and uses, to water gains accrued directly and indirectly from the provision of other services of each of these ecosystems.

5. Assess biodiversity components of current and potential economic significance, especially in freshwater ecosystems and climatic transition zones inhabited by peripheral populations, and determine the water allocation (including ground water resources and local runoff), as well as the extent of land and its spatial configuration, required for their conservation.

6. Conduct long-term studies to evaluate the effects of damming storm water on biodiversity at the lower reaches of watersheds, especially in dryland regions, and use the results to prescribe water quantities that must be released to reduce damages to downstream biodiversity component, and thus secure their involvement in identified service provision.

7. Evaluate the amount of water lost through appropriation of different ecosystem types by agriculture and urban development, for generating guidelines to be followed in land use allocation in areas planned for future development.

8. Study the rate of change of population sizes and number of species of species due to fragmentation, transformation and reductions in size of “natural” ecosystems, and use the results to provide guidelines for placement, size and spatial configuration of projected land uses and transformation under different development scenarios.

9. Evaluate the amounts of water allocated to protected areas and for supporting biodiversity in other areas, and the fraction of this water that recharges groundwater and hence can be reused, and assess the rate of service provision by protected areas to non-protected ones.

10. Study the role of freshwater ecosystems in treating wastewater of various qualities, the degree to which freshwater allocated to natural ecosystems can be replaced by treated wastewater, and the technologies appropriate for this substitution.

11. Conduct the research required to define improved criteria for evaluating the significance of biodiversity in providing ecosystem services, including the degree of redundancy to be expected under various circumstances.

Management recommendations

1. Planners need to internalize that allocating water to freshwater ecosystems is not a concession to the "greens" or done just for aesthetic and recreational objectives, but it is a pre-requisite for making the planned development sustainable, when different spatial and temporal scale are pre-defined for addressing the aspired sustainability.

2. In planning a development project or in reviewing it, include all "externalities" in the project's costs and especially the expected reduction in service provision rate, at several spatial and temporal scales. These reduced rates need to be translated to projected costs to other, existing and projected development and to the value of the reduced opportunity.

3. Water allocations to ecosystems should be based on pre-determined goals in the state and trends of services of these ecosystems. Benchmarks and indicators for the provision of these services and monitoring programs for each of the water-allocated ecosystems should be developed to review and update the allocations.

4. When ecosystems of special significance, such as those in climatic transition areas or those supporting progenitors and relatives of cultivated crops are targeted for water-driven development, it would be prudent to consider setting aside within them protected areas sufficiently large to serve as repositories of genetic resources.

5. The costs and benefits of avoiding, reducing, or mitigating the effects of ecosystem fragmentation by a projected development projects needs to be evaluated against different degrees of the aspired sustainability of the project and of the resulting human well-being.

6. Projections of the local and regional effects of global climate change on water-related and other ecosystem services need to be consulted and considered in the planning, execution, operation and monitoring of current land uses and projected development projects.

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