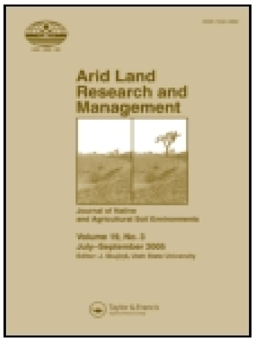

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Henry N. Le Houerou

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Restoration and Rehabilitation of Arid and Semiarid Mediterranean Ecosystems in North Africa and West Asia: A Review

HENRY N. LE HOUÉROU

International Consultant in Arid Land Ecology, Management, and Development

Mediterranean-type vegetation and ecosystems have undergone intense processes of degradation for decades, centuries, or millennia under heavy and prolonged pressure from human and livestock populations. An extensive literature on exclosures, afforestation, reafforestation, rehabilitation, and other regeneration operations over several million hectares in Mediterranean bioclimatic areas from the Atlantic Ocean to the Aral Sea, combined with 50 years of personal field experience, allowed us to draw a number of conclusions on the consequences of these efforts, constraints, and limitations: (1) *Exclosure usually permits the restoration and biological recovery of vegetation structure, composition, biomass, and productivity in a time span of 3–5 years in steppic ecosystems and 25–30 years in coniferous or sclerophyllic vegetation areas. There are exceptions, however, when vegetation is so degraded to the level that it has reached a new metastable equilibrium, characterized, e.g., unpalatable range weeds, perennial dwarf ephemeroids, cryptogams, or soil surface sealing by raindrop splash or other physical or biological factors.* (2) *Controlled access and rationally managed utilization of the land may achieve similar and sometimes better results than full exclosure.* (3) *Afforestation and reafforestation are usually successful above the isohyet of 200 mm* a^{-1} *precipitation and, occasionally, at a lower annual precipitation, where the species introduced or reintroduced is appropriate and the causes for degradation have been discontinued or seriously mitigated.* (4) *Rehabilitation operations, including water and/or soil conservation, may quickly achieve spectacular results but at a higher cost and subjected to a number of constraints pertaining to the techniques utilized and adequate subsequent management.* (5) *The main constraint for success is the discontinuation of situations that have caused degradation. The most difficult to overcome usually are of a socioeconomic and/or sociocultural nature. The speed of biological recovery is commensurate* (inter alia) *with the rate to which this constraint is overcome.* (6) *The present land surface concerned with regeneration* (*restoration + rehabilitation*) *in this part of the world represents ca.* 4×10^6 *ha, representing some 6% of the actual "forest and woodland" in these areas. The National Regeneration Effort* (*NRE*), *a novel concept, is evaluated by using the ratio between the Annual Regeneration Expenditure* (*ARE*) *and both the Annual National Budget Expenditure* (*ANBE*) *and Gross National Product* (*GNP*).

Keywords afforestation, biological recovery, exclosure, plant communities, reafforrestation, regeneration, vegetation dynamics

Received 30 July 1998; accepted 19 November 1998.
Address correspondence to Dr. Henry N. Le Houérou, 327 Rue de Jussieu, F-34090 Montpellier, France. E-mail: houerou@mnet.fr

Present Status of Native Vegetation and Natural Ecosystems in the Study Area

Mediterranean-type vegetation and ecosystems herein are understood in the sense of Emberger (1955) and his school, i.e., related to Mediterranean bioclimatic conditions with winter rain and summer drought, extending from the Atlantic Ocean to the Aral Sea between 30° and 45°N latitudes. The terms of regeneration, restoration, rehabilitation, and biological recovery follow the definitions by Le Houérou (1997a, b, 1981, 1995a, b, 1996a, b), by Aronson et al. (1993a, 1996), and by Le Floc'h et al. (1996).

The present dynamic status of native vegetation in the Mediterranean basin was reviewed in some detail by the present author some 20 years ago (Le Houérou, 1977a, 1980, 1981). The situation has not improved since that time, quite the opposite: natural forest has receded by an approximate 2% per annum, i.e., corresponding to a logarithmic 50% areal reduction over a period of 35 years. A similar situation has occurred with the Mediterranean steppic vegetation, both in the Irano-Turanian and the Ibero-Maghribian phytogeographic provinces (Le Houérou, 1992a, b 1995a, b, c). The degradation processes have been analyzed repeatedly from various perspectives (Le Houérou, 1962, 1968a, 1969a, 1992b, 1995b, 1996c).

The situation, however, differs considerably to the north and to the south of the Mediterranean basin: the rate of reafforestation increases by an approximate annual 0.5% to the north, due to land abandonment, while in the south it decreases by about 2%, as mentioned above (Le Houérou, 1981, 1990a, b; Bourbouze, 1982; Boutonnet, 1989). In the sclerophyllous and coniferous Mediterranean vegetations of the semiarid to subhumid biozones with 300–800 mm mean annual rainfall (MAR), the processes of forest degradation (including steppization) were analyzed in detail in terms of simultaneous evolution of vegetation and soil (Le Houérou, 1969a). Later studies (Floret, 1981; Aïdoud 1989, 1994; Gauquelin et al., 1996; Telahique et al., 1987) supported these results. Soil erosion figures, naturally, are correlated to vegetation and ecosystem depletion (Le Houérou, 1969a, 1992a, 1993b, 1993c). Forest biomass may thus have decreased from 100–300 Mg dry matter (DM) ha^{-1} in close to pristine primeval forest to 1–4 Mg DM ha^{-1} in degraded garrigues, phryganas, or bathas, while perennial canopy ground cover dropped from 80–100% to 10–20%. At the same time, soil erosion may have increased from a few hundred kg ha^{-1} a^{-1} to up to 50–55 Mg ha^{-1} a^{-1} at the river basin watershed scale, and much more locally (Le Houérou, 1969a).

In the steppic vegetation of the arid Mediterranean zones of the Ibero-Maghribian and Irano-Turanian biogeographic provinces, the degradation has dramatically evolved at approximately the same pace as in forests and shrublands (ca. 2% per annum) due to clearing for cultivation of cereals, firewood collection from dwarf shrubs, and heavy overgrazing. It has still considerably worsened by the recent widespread development of complementary feeding of small ruminants with grain and concentrate feed, through which fiber-hungry animals wander in large numbers over destroyed rangelands (Le Houérou, 1962, 1965, 1968b, 1975, 1977c, 1992b, 1993a, 1998a; Pabot, 1962; Pearse, 1970, 1971). The perennial canopy ground cover and perennial phytomass have receded from 20–25% and 1000–1500 kg DM ha^{-1} to 2–5% and 200–500 kg DM ha^{-1}, respectively, in some 50 years (Le Houérou, 1969a, 1972, 1986, 1992a, b, 1995a, b; Floret & Le Floc'h 1983; Aïdoud, 1989, 1994). In the chamaephytic Mediterranean steppe zone, perennial canopy cover is closely correlated with perennial phytomass, each percent of canopy cover corresponding to 43 ± 3.6 kg DM ha^{-1} (Le Houérou, 1987).

Regeneration

Regeneration of a depleted land includes two main procedures: (1) restoration of ecosystems to their pristine situation, also called biological recovery or remontée biologique (Monjauze & Le Houérou, 1965), and (2) land rehabilitation, which corresponds to reclamation through a new ecosystem different from the natural predegradation situation, at least in terms of floristic composition (Le Houérou, 1977a, b, 1981, 1995a, b, 1996c; Aronson et al., 1993b; Le Floc'h et al., 1996).

Restoration

Restoration, in turn, includes also two main procedures: (1) exclosure, which means that the area under consideration is protected from humans and livestock intrusion, usually by fencing, and (2) afforestation and reafforestation, on the other hand, mean artificial planting of trees or shrubs and their subsequent protection, at least on a temporary basis, from human and livestock.

Exclosure

Exclosures are areas of natural vegetation protected from the intrusion of major degradation agents, such as humans, livestock, and big game, but usually not from all herbivores, such as lagomorphs, rodents, insectivora, mollusca, birds, and insects. This protection may be absolute or relative, temporary, subpermanent or permanent. Subpermanent exclosures are exemplified by the periodical opening of protected areas to users in limited numbers for a given period, especially during time of drought. This practice was traditional in Arabia, where it was known as ahmia (plural *hema*) in historical times and also in North Africa under the name of *agdal* or *gdal*. Unfortunately, those have become obsolete in both West Asia and North Africa; efforts to revive them did not meet with much success (Le Houérou, 1962; Draz, 1978). Vegetation usually responds very strongly to exclosure, even at desert conditions with MAR as low as 60–80 mm, provided the soil is deep and permeable (Le Houérou, 1962, 1968a, 1983, 1993b, 1998d; Le Houérou & Gillet, 1985; Gillet & Le Houérou, 1992; Kernick, 1966; Floret, 1981; Telahique et al., 1987).

Controlled access and limited grazing may produce similar effects, or even better than exclosure in some cases. A long-term protection may result in a negative effect with respect to light grazing because of the excessive development of individual plant species in rainy years, which afterwards requires more water than the environment can offer, hence occasional dieoff (Le Houérou, 1962, 1995b, 1998b,c). Light grazing thus seems a positive factor in sustainable land and ecosystem management, at least in the arid zone. Yet it is difficult to generalize, as appropriate management may require temporary heavy grazing to control least desirable species.

From the comparison of many large-scale exclosures across the whole region from Morocco to Iran, it appears that perennial ground cover and primary productivity are enhanced by a factor of 2–5 and, in most cases, 3–4 in a time frame of a few years of total or partial protection (Le Houérou, 1962, 1975, 1977a, b, 1986, 1996a; Le Hourérou & Gillet, 1985; Le Houérou & Hoste, 1977). In Libya, for instance, the perennial plant cover, phytomass, and productivity of six large range development project areas totaling 167,300 ha increased by three-fold in a time span of 3–5 years, with a spectacular development of perennial forage bunch grasses (*Stipa* spp.) at MAR of 120–220 mm (Le Houérou et al., 1983). In Morocco, 20 large-scale temporary exclosures established in the steppic highlands of the eastern-central part of the country, above a total of 450,000 ha, over a time span of 3–5 years showed a mean increase of perennial phytomass by an estimated factor of 5. There, the rain use efficiency (RUE) factor was 5 kg DM ha^{-1} a^{-1} mm versus 1 kg in nonprotected areas, while the average perennial basal cover increased by a factor of 8, i.e., 40% versus 5% (Lazarev et al., 1995). Such figures are by no means exceptional under similar circumstances (Le Houérou, 1962, 1969a, b, 1977b, c, 1985). In

TABLE 1 Afforestation, reafforestation, and rehabilitation in North Africa

System	Algeria	Libya	Morocco	Tunisia	Total
	Country				
Natural forest and shrubland	238,174	17,595	44,630	15,536	474,294
Afforestation + reafforestation					
Pinus halepensis and other conifers	928	30	310	218	1486
Eucalyptus spp.	52	30	180	42	304
Acacia cyanophylla	20	60	40	90	210
Total afforested + reafforested[a]	1000	120	530	350	2000
Afforestation + reafforestation, % of national forests	32	24	10	55	21
Rehabilitation (fodder shrubs)	10	40	20	350	420
Total regeneration (except exclosures)	1010	160	550	700	2420
Total regeneration, % of national forests	32	32	10	110	25
Total regeneration, % of land area	0.4	0..1	1.2	4.5	0.5

[a] Holloway (1991) published the following values in 10^3 ha: Algeria 650, Morocco 443, Tunisia 220. These values seem quite comparable to those listed here, taking into consideration that they are about 10 years older.

Sources: FAO (1982, 1996), Marchand (1990), Sari (1977, 1995), Challot (1978), Le Houérou and Pontanier (1987), Ghazi and Lahouati (1997), DGF Algérie (1997), DGF Tunisie (1995), A. Aïdoud (personal communication, 1998), R Aïni (personal communication 1998), O. Berkat (personal communication, 1998).

West Asia and North Africa a review of 46 range production experiments from 11 countries showed that productivity in exclosures averaged 2.8 times that of adjacent grazed areas, with a RUE factor of 5.4 ± 0.5 kg DM ha^{-1} a^{-1} mm^{-1} versus 1.9 ± 0.2 kg DM ha^{-1} a^{-1} mm^{-1}, while the variability of annual production decreased by 5% in the exclosures versus the grazed areas (Le Houérou, 1998d).

The total area under temporary or permanent exclosure in the study zone amounts to several million hectares, e.g., 750,000 ha in Morocoo, 890,000 ha in Saudi Arabia, 450,000 ha in Tunisia, 85,000 ha in Algeria (plus 8 million ha of the more or less virtual Tassili Desert Park) (Bousquet, 1992). These areas include national parks and other actually protected zones. The national regeneration effort (NRE) was 1.25% for Tunisia, 0.7% for Algeria, and 0.3% for Morocco, as expressed in percent of the annual national budget expenditure. Expressed in percent of gross national product (GNP), this effort was approximately 0.5% for Tunisia, 0.2% for Morocco, 0.1% for Algeria, and 0.04% for Libya.

Afforestation and Reafforestation

Reafforestation, i.e., the planting of former forest land with native species, differs from afforestation, which is concerned with the planting of trees or shrubs on land that has not been forested in recent times (but could have been so in ancient times), irrespective of whether the species selected are native or exotic, e.g., Aleppo pine

(*Pinus halepensis* Mill.) versus Monterrey pine (*Pinus radiata* D.Don), eucalypti, or wattles. Both afforestation and reafforestation have been very active in most countries of the region since the 1960s. Sometimes it has started earlier from the second half of the 19th century in Algeria or from the 1920s in Libya, Tunisia, Morocco, Syria, Jordan, Israel, and Turkey. It has been concerned with some 4 million ha throughout the study area, i.e., some 6% of the naturally forested area in my estimate, and over 2.5×10^6 ha in North Africa alone, i.e., about 25% of the native forest of that subregion. Reafforested areas are often successfully protected against the main degrading agents, i.e., humans and livestock by the routine activities of National Forest Services. They may thus reach the stage of pristine-like formations in a time span of 25–50 years, depending on climate, soil, and above all, the efficiency of the protection. Afforestation and reafforestation figures are difficult to come by and often frustrating. The areas affected are large; in my "educated guesstimate" they may cover approximately the areas in Algeria, Libya, Morocco, and Tunisia as shown in Table 1. For Algeria, for example, Bensaïd et al. (1998) published the official government figures for the year 1984 (Table 2).

As one can see from Tables 1 and 2, the situations are very different from one country to the next. The high figure of 350,000 ha for fodder shrub species in Tunisia comes essentially from some 300,000 ha of privately owned cactus plantations in the central western part of the country (Sbeitla–Kasserine–Thala). The currently planted area is ca. 60,000 ha per annum in Algeria (of which 65% are considered as successful afforestation/reafforestation, but only 36% in the so-called highlands "Green Belt," i.e., between 30,000 and 38,000 ha in net figures), 25,000 ha in Tunisia, and 30,000 ha in Morocco. The cost of afforestation is ca. US$ 1000 ha^{-1}, when handmade, and ca. US$ 1600 ha^{-1}, with mechanical land preparation (ripping, bulldozing).

The so-called Green Belt of Algeria, planted to Aleppo pine by the army in the 1970s and 1980s, meant to combat desertization in the steppic highlands between

TABLE 2 Afforestation and reaforestation in Algeria (Bensaïd et al., 1998)

Species	Area (10^3 ha)	Volume m^3	Volume $m^3\ ha^{-1}$
Fully forested areas			
Aleppo pine (*Pinus halepensis*)	881.3	856	0.97
Eucalyptus spp. (mainly *E. globulus* Labill. & *E. camaldulensis* Dehnh.)	40.2	147	3.65
Deciduous oaks (*Quercus faginea* Lam., *Q. afares* Pom.)	48.0	127	2.64
Atlas cedar [*Cedrus atlantica* (Endl.) Manetti]	19.5	67	3.46
Holm oak (*Q. ilex* L.)	108.0	52	0.48
Maritime pine (*Pinus pinaster mesogaeensis* Gauss.)	31.5	29	0.90
Total	1128.5		
Garrigue and Maquis	1981.5 [= 3151 − (1128.4 + 40.2)]		
Reforested area 1962–1987	461.8 (annual average = 38.4×10^3)		

the isohyets of 200 and 300 mm MAR, affected a total of 123,000 ha. It is considered by the National Forest Service as a 36% effective afforestation, i.e., a net result of 44,200 ha actually afforested (mostly around Djelfa with 300–350 mm MAR). The rate of success of afforestation, i.e., the quotient between the hectarage successfully established by the area actually planted is low to fairly low, with the exception of Tunisa. According to the figures published by Holloway (1991) and Benabid (1991), the rate of success in Morocco is about 60%, probably around 50% in Algeria (65% in the semiarid to humid biozones and 36% in the arid zone (Bensaïd et al., 1998; Aïdoud, personal communication, 1998), and 80% in Tunisia, where a great effort has been made on the improvement of nursery techniques and in site preparation (R. Aïni, personal communication, 1998). In other words, huge amounts of money are actually wasted annually.

The afforestation/deforestation balance is currently positive only in Tunisia, by some 5000 ha a^{-1}; it is considered to be negative by approximately $-20{,}000$ ha a^{-1} in Algeria and $-30{,}000$ ha a^{-1} in Morocco (the author's estimate). Afforestation with exotics, e.g., eucalypti, wattles [*Acacia* (*Racosperma*) spp.] and mesquite (*Prosopis* spp.) plantations, are obviously not a restoration but a rehabilitation. Eucalyptus woodlands, for instance, evolve toward dense stands of closed monospecific plantations with no understory, unlike the reintroduced native tree species. Some of the exotics seem to develop allelopathy (teletoxicity) to native plants, with perhaps the exception of the perennial grasses *Oryzopsis miliacea* (L.) Benth&Hook, *O. thomasii* (Duby) da Silva, *O. paradoxa* (L.) Nutt., *O. coerulescens* (Desf.) Hack, which are often found abundant in *Eucalyptus* spp. groves, across the region. Similarly, dense stands of *Acacia* (syn. *Racosperma*) *cyanophylla* Lindl. are also deprived of understory, perhaps for the same reason. Afforestation with *Eucalyptus* spp. represented some 2.5×10^6 ha in the entire Mediterranean basin and some 400,000 ha, i.e., 0.8%, of the 52 million ha of native forest in the area under consideration, in the mid-1970s (FAO, 1982).

Rehabilitation

Rehabilitation pertains to the artificial establishment of a new type of vegetation, different from the pristine native type that had been degraded or destroyed (Le Houérou et al., 1992). This is usually achieved through the artificial planting of exotic or subnative species: trees, shrubs, and herbs. Subnative connotes species native to a neighboring isoclimatic region but not really "native" strictly speaking, such as Near East endemics in North Africa and vice versa. Among the most utilized are eucalypti (*Eucalyptus* spp.), Monterrey pine (*Pinus radiata*), *Acacia* (syn. *Racosperma*) *cyanophylla* [= *A. saligna* (Labill.) Wendl.], some saltbushes, such as *Atriplex nummularia* Lindl., *A. canescens* (Pursh) Nutt., *A. lentiformis* (Torr.) S. Wats., *A. amnicola* P. G. Wilson, *A. undulata* D. Dietr., cacti (*Opuntia ficus-indica* f. *inermis* (Web.) Le Houér. and var. *amyclaea* (Tenore) A. Berger), agave (*Agave americana* L.), mesquites or algarrobos (*Prosopis* spp.), and many others.

The scope of rehabilitation may be diverse, e.g., for production of timber (*Eucalyptus* spp., *Tamarix stricta* Stev. ex Bge., *Conocarpus lancifolius* Engl. & Diels), firewood (*Acacia cyanophylla*, *Tamarix* spp., saltbushes), browse (species of *Acacia*, *Atriplex*, cacti, *Agave*, *Myoporum*, *Colutea*, *Chamaecytisus*, *Prosopis*, *Medicago* agg. *arborea* L.) landscaping (species of *Acacia*, *Eucalyptus*, *Lagunaria*, *Myoporum*, *Atriplex*, *Parkinsonia*), wind breaking (*Casuarina* spp., *Tamarix* spp.), sand dune fixation (species of *Acacia*, *Haloxylon*, *Tamarix*, *Eucalyptus*), salt-land reclamation and utilization of brackish water areas (various species of *Atriplex*, *Myoporum*, *Lagunaria*, *Phoenix*, *Elaeagnus*, *Tamarix Haloxylon*), street and roadside plantations, beekeeping and honey production (species of *Eucalyptus*, *Parkinsonia*, *Prosopis*, *Melaleuca*), hedgerows and land partitioning (*Agave* spp., *Acacia* spp., spiny cacti), erosion control, and fruit production for human consumption (cacti, *Ziziphus*, spp., *Capparis* spp.), These may be established with or without the assistance of soil and water conservation techniques, or even with water harvesting or runoff farming techniques (Evenari et al., 1982); they may then exhibit a productivity many times larger than the pristine vegetation (Lé Houérou, 1990c, 1994). Artificially established stands, particularly of exotics, exhibit, however, slow growth and low productivity unless they are protected from the competition by natural vegetation, at least in the early stages of establishment (Le Houérou et al., 1992). Because of that, the species used may be combined with crops in alley-cropping systems, with cereals, for instance, even in quite arid conditions with or without runoff farming techniques (Le Houérou, 1990c, 1993b, 1994).

So far, range reseeding has produced few positive results in arid zones because of three major constraints:

- lack of available seed material from adapted native species (e.g., *Artemisia herba-alba* Asso), exotics usually having failed, with very few exceptions at particular conditions of cold winter highlands of Morocco and Iran;
- technical difficulties of establishment due to low, erratic, and unpredictable rainfall; and
- subsequent inadequate management of sown pastures.

Even the establishment of ley farming with self-reseeding annual legumes such as subclovers (*Trifolium* spp.) and medics (*Medicago* spp.), so successful in Australia, did not extend to large areas. Perhaps there are less than 30,000 ha in the whole basin, in spite of the hundreds of millions of US$ spent to popularize them among farmers over the past 30 years by various international and bilateral cooperation agencies (Le Houérou, 1969b).

In the semiarid and humid zones, however, the establishment of sown perennial pastures is technically easy by using species such as *Festuca elatior* L. spp. *arundinacea* (Shreb.) Hack. (tall fescue). *Oryzopsis miliacea* (smilo), *O. holciformis* (M. Bieb) Hack., *Agropyron* spp. (wheatgrasses), *Lolium* spp. (ryegrass), *Dactylis glomerata* L. (orchard grass), *Phalaris tuberosa* var. *stenoptesa* (Hack.) Hitche (Harding grass), *Cenchrus ciliaris* L. (buffelgrass), *Bromus unioloides* Kunth (rescue grass), *Lotus corniculatus* L. (trefoil), *Onobrychis viciifolia* Scop. (sainfoin), *Medicago sativa* L. (lucerne), *Hedysarum* spp., *Melilotus* spp. (sweet clovers), *Trifolium pratense* L. and *T. repens* L. (red and white clovers), *T. fragiferum* L. (strawberry clover), *Poterium sanguisorba* L. (burnet), and many others (Le Houérou, 1969b). This technique, albeit simple, successful, and amenable to a very high productivity, with RUE factors of up to 10 kg DM ha^{-1} a^{-1} mm^{-1}, did not really take among farmers either, perhaps for sociological reasons (fear of innovation, changes in crop rotation, new farm equipment requirement, changes in routine operations, etc.), and also for commercial considerations, such as the comparative prices and terms of trade between animal and vegetal products and cost-benefit ratios (Le Houérou, 1968b).

Rehabilitation may produce very spectacular results with a biomass productivity manifold larger than the pristine vegetation, subject to the fulfillment of a number of constraints, namely, (1) selection of site-adapted species, populations, accessions, strains, and cultivars; (2) elimination or serious mitigation of the causes that brought the degradation about; and (3) subsequent rational management of rehabilitated areas (Le Houérou, 1969b, 1995a, b; Le Floc'h et al., 1996).

The cost of rehabilitation with woody species may be very high when using the classical techniques of establishment of nursery-grown seedlings (US$200–2000 equivalent per ha). Most farmers and stockmen cannot afford such costs. Therefore research efforts must be devoted to develop cheaper methods, such as the direct seeding of pregerminated seeds in a moist soil using an opportunistic strategy to act quickly when favorable weather circumstances occur. In turn, this assumes that the seed production problem has been solved, since these techniques require many more seeds than the routine nursery–transplanting practice (Le Houérou, 1994, 1997, 1998d). Mechanical planting of bare–root seedlings, mechanical sowing, etc., also may be used (Le Houérou, 1994).

Regeneration Effort

Over 4 million ha of degraded arid land have been restored and rehabilitated in the eastern and southern parts of the Mediterranean basin over the past four decades. They represent an investment of about US$4 billion in 1998. Some countries, such as Tunisia, fare very well, devoting serious efforts to afforestation and rehabilitation, with an annual expenditure of some US$50 million, i.e., about 1.25% of the annual expenditure in the state overall budget of ca. US$4 billion (Aïni, personal communication, 1998). In Algeria the figure is 0.07% of the annual budget expenditure (US$9.5 billion); in Morocco the proportion is about the same as in Algeria. Better and cheaper establishment methods, however, should make it possible to greatly improve the efficiency of restoration and rehabilitation operations, thus rendering them affordable to individual farmers, foresters, and stockmen, hence sustainable in the long term.

Changes in the traditional land tenure systems toward privatization of communal lands, although still very slow, are already under way in several countries. One may therefore reasonably hope that these will move the situation for the better in the not too distant future (Le Houérou, 1997, 1998a).

Conclusions

In the region under consideration, Mediterranean–type vegetation and ecosystems have undergone intense processes of degradation for decades, centuries, or millennia, depending on the area, under heavy and prolonged pressure from human and livestock populations. A systematic analysis of the literature on exclosures, afforestation, reafforestation, rehabilitation, and other regeneration operations over several million hectares in thousands of areas, some dating back to over a century, combined with 50 years of the author's personal field experience in 17 of the 20 countries concerned, allow us to draw a number of conclusions on the consequences of these efforts, their successes and failures, constraints and limits. These may be formulated as follows.

1. Exclosure usually permits the restoration and biological recovery of vegetation structure, composition, biomass, and productivity in a time span of 3–5 years in steppic ecosystems and 25–30 years in coniferous or sclerophyllic vegetations. As always, there are exceptions to that rule when vegetation is so degraded that it has reached a new metastable equilibrium characterized, for instance, by unpalatable range weeds or perennial dwarf ephemeroids or cryptogams, such as lichens and mosses, that may cover most of soil surface, and by soil surface sealing by raindrop splash, biological soil surface sealing by cyanobacteria, etc.
2. Controlled access and rationally managed utilization of the land may achieve the same, and sometimes better, results than full exclosure, either in the short or long term.
3. Afforestation and reafforestation are usually successful above the isohyet of 200 mm mean annual rainfall, and sometimes far below that limit, as long as the selection of the species introduced or reintroduced is appropriate (e.g., species of native genera of *Pinus*, *Tetraclinis*, *Juniperus*, *Acacia*, *Pistacia*, *Argania*, *Haloxylon*, *Calligonum*, *Tamarix*) and the degradation causes have been discontinued, or at least seriously mitigated (these include overstocking, wildfires, clearing, overfelling, overcollection of fuelwood or medicinal plants, etc.).

4. Rehabilitation operations with or without water and soil conservation may quickly achieve spectacular results but at a higher cost and subject to a number of constraints pertaining to the techniques utilized: appropriate association between species and site selection and, most important, adequate subsequent management.
5. The main constraint in meeting success is the discontinuation of the situations that brought degradation about. Those are also the most difficult to overcome, as they usually are of a socioeconomic and/or sociocultural nature. The speed of biological recovery is commensurate (inter alia) with the rate to which this constraint is overcome.
6. The present land surface concerned with regeneration (restoration + rehabilitation) in this part of the world represents in the vicinity of 4×10^6 ha, i.e., some 6% of the actual "forest and woodland" in these areas (52×10^6 ha in 1995, according to the statistics published by FAO, 1996). The National Regeneration Effort, a novel concept, is evaluated through the ratio between the annual regeneration expenditure and (1) annual national budget expenditure and (2) gross national product. The figures for the five countries of North Africa vary from 0.3 to 1.25% for the former and 0.1–0.5% for the latter.

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