Annals of Arid Zone 57(3&4): 191-200, 2018

Opportunities, Limitations and Gaps in the Ecological Restoration of Drylands in Argentina

C.A. Busso[1]* and D.R. Pérez[2]

[1]*Universidad Nacional del Sur, San Andrés 800, 8000 Bahía Blanca, Buenos Aires, Argentina*

[2]*National University of Comahue, Neuquén, Argentina*

Received: April 2018

Abstract: This paper reviews the opportunity to ecologically restore, impaired dryland ecosystems in Argentina. This is very important because ecological restoration may contribute to (1) control the effects of desertification and (2) reverse the complex social consequences of the degradation. Reported benefits and limitations, as well as gaps, in the ecological restoration of drylands in Argentina are discussed. The analyzed restoration papers were grouped into: (1) prescribed natural regeneration (2) assisted natural regeneration, partial reconstruction and (3) complete restoration. Based on comparison with results from other drylands of the world, we evaluated possibilities of applying some practices to fill the ecological gaps. Finally, we discuss costs and social aspects for the restoration of the studied region.

Key words: Branching, direct seeding, natural regeneration, plantation, topsoil.

Rehabilitation and ecological restoration are critical to (1) control the effects of desertification on the biophysical environment and (2) minimise the complex social and ecological constraints which involve 2.5 billion people worldwide (Reynolds *et al*., 2007; James *et al*., 2013). International programes widely recognize that dryland restoration is the key to reverse the current global dryland degradation, ensuring at the same time a future global sustainability (UNCCD 1994; James *et al*., 2013).

The Patagonia region of Argentina (41°48’36.54” S -68°54’22.57” W) has 78.5 million ha of arid and semi-arid ecosystems, of which 73.5 million (93.6%) are desertified by cattle ranching and hydrocarbon extraction activities. Mazzoni and Vazquez (2009) mentioned that the desertification varies from mild (9.3%), moderate (17.1%), moderate to severe (35.4%), severe (23.3%) to very severe (8.5%). Due to the urgent need to reverse these high levels of degradation, recent advances of knowledge for rehabilitating and restoring this region, the following review analyzes the current situation and considers the options to reach the objectives of recovery of degraded lands.

Prescribed Natural Regeneration

Prescribed natural regeneration is an ecological restoration in which project tasks include no biophysical manipulations or other direct interventions. The major intervention in prescribed natural regeneration projects consists of removing the sources of disturbance (e.g., control of grazing by livestock), for as long as necessary to allow the natural recovery process to occur (Clewell and Aronson, 2013).

The palatable grass *Bromus pictus* has been proposed as an excellent example of the benefit of prescribed natural regeneration in the steppes of Patagonia for the overall sustainability of these agroecosystems and restoration of natural capital (Aguiar and Roman, 2007). Their study showed the economic benefit of fencing to exclude grazing to facilitate regeneration of the palatable grasses and enhance the ecological benefits for other plant species, fauna and local people. According to the analysis of Aguiar and Román (2007), financial and economic costs can be affordable on the largest farms, while small producers could adopt it with the help of training and subsidies.

The ecological concepts and perspectives underpinning the development and application of state-and-transition models, thresholds and rangeland health are well documented (Briske *et al*., 2005). Various studies of state-and-transition models have been reported as useful for designing management plans for the restoration of pastures in drylands of Patagonia and in the phytogeographical Province of the Caldenal in Argentina (Bonvissuto, 2008; Distel, 2016). However, it has been claimed for

*E-mail: carlosbusso1@gmail.com

some environments, like the Monte in North Patagonia, that restoration of highly diverse vegetation patches (e.g., those of *Chuquiraga hystrix*) is very likely uncertain (Bisigato and Bertiller, 1997). The integration of indicators of landscape functional analysis into a structural-functional state-and-transition model in western Patagonia allowed the analysis of resistance, resilience and stability in response to disturbance factors (e.g., overgrazing). This information was used to define states in stable, unstable, mixed-unstable and indifferent-stable dynamic equilibriums. The approach provided a tool for ecosystem assessment regarding the identification of states that can be restored and those that might be more susceptible to degradation (López *et al.,* 2013). The concept of thresholds (Friedel, 1991) was helpful in the determination of priorities and predicting likely success rates. Threshold identification is necessary for recognition of the various stable plant communities that can potentially occupy an ecological site. However, thresholds are difficult to define and quantify because they represent a complex series of interacting components, rather than discrete boundaries in time and space (Briske *et al*., 2005).

Application of these theoretical frameworks faces social and ecological difficulties. A number of challenges are encountered when (1) plant growth is constrained because of a low soil water availability and forage production is highly variable among years, (2) movement of livestock is difficult, (3) the land subdivision or the availability of watering points on rangelands is scarce, (4) financial difficulties and (5) cultural constraints and lack of adult educational programs (Golluscio *et al*., 1998; Pérez and Farinaccio, 2013; Pérez *et al.,* 2018).

Prescribed natural regeneration is more difficult or impossible when the initial state is characterized by (1) the absence of vegetation and (2) deeply disturbed soils, as is the case of disturbances caused by oil industries. For example, Zuleta *et al*. (2003) reported that even 40 years post-disturbance by the oil industry, regeneration of the natural ecosystem (Monte Austral) did not reach acceptable levels (75% similarity with the reference sites). However, studies carried out on slopes pointed out that the process of regeneration involves several factors together; the passage of time by itself would not be enough to interpret the natural recovery of severely degraded environments (Massara Paletto *et al.,* 2013). Natural regeneration was higher in some regions than in others in the Patagonia steppe (Rueter and Rodriguez, 2013). This indicates that different biogeographical districts, slopes and soils of drylands of Patagonia could generate great differences in resilience and possibilities of prescribed natural regeneration in very severely degraded sites. In the Mojave desert in the United States, Abella (2010) reported that the time estimated by 29 individual studies for the full reestablishment of total perennial plant cover was 76 years. Sites in the Mojave desert have characteristics similar to those in the "Monte" (Busso and Bonvissuto, 2009), Although long period this time was shorter than the estimated 215 years (among 31 individual studies) required for the recovery of all the species composition typical of undisturbed areas in that desert, assuming that recovery remained linear following the longest time from disturbance measurements made by the studies.

Despite the socio-economical and cultural constraints, there are motivations to continue socio-environmental investigations that might facilitate prescribed natural regeneration because it is a relatively low-cost option and has a high feasibility.

Assisted natural regeneration, partial reconstruction and complete restoration

Use of soil amendments and branching (covering all, or selected parts, of a treatment area with dead branches and leaf litter to create a microenvironment conducive to seedling establishment; Tongway and Ludwig, 1996) in assisted natural regeneration are the main component of this approach. Partial reconstruction is used when the scale of intervention is high and it involves technical solutions (mechanical interventions such as soil scarification techniques) and natural regeneration to repair the degraded environment (Clewell and Aronson, 2013).

Soil amendments: Kowaljow and Mazzarino (2007) described results of the effect of composted materials of different origin (biosolids [BC] and municipal organic wastes [MC]) with a variable final particle size (screened versus unscreened) to study restoration of soils (burned by a wildfire) after 6 to 12 months of the application at the field in semi-arid NW

Patagonia. Application of composts was at 40 Mg ha^{-1}. These authors also included a fertilizer treatment with soluble N (100 kg ha^{-1}) and P (35 kg ha^{-1}) and an untreated control. Chemical (electrical conductivity, pH, organic C, total N, extractable P), biological (potential microbial respiration, potential net N mineralization, N retained in microbial biomass) and physical (temperature and soil moisture) properties were determined (Kowaljow and Mazzarino, 2007). The plant-soil cover was also estimated. Although more evident after the wet season (12 months of application), soil chemical and biological properties showed a high response to organic amendment addition. As biosolids compost (BC), and soil pH with municipal composts (MC) increased, soil organic C, total N and extractable P also increased significantly (Kowaljow and Mazzarino, 2007). Potential microbial C respiration and net N mineralization were similar for both MC and BC and significantly higher than in the control and the inorganic fertilized treatment (Kowaljow and Mazzarino, 2007). Inorganic fertilization improved plant cover more than organic amendments, but it did not contribute to soil restoration (Kowaljow and Mazzarino, 2007).

Use of top soil: The strategy of top soil transporting to degraded sites seeks to introduce (at low cost) soil microflora and microfauna, various disseminule sources and nutrients into the ecosystem to restore (Golos *et. al*., 2016). This promising technique has not yet been evaluated in Patagonia, although some research is currently undergoing on it.

Branching: Tongway and Ludwig (1996) showed that the use of plant branches was successful in restoring a degraded woodland. This rehabilitation procedure had been initially designed to re-establish resource control processes (Tongway and Ludwig, 1996). The procedure comprised of laying piles of branches in patches on the contour of bare, gently sloping landscapes, with the expectation that soil, water and litter would accumulate in between these branch piles. This increased soil habitat and its productive potential. The procedure was derived from landscape function analysis, indicating that surface water flow was the major mean of resource transfer in these landscapes.

In Patagonia, tests were carried out on the placement of branches at sites with a clearance of the vegetation and with compacted soil because of the construction of oil industry pipelines (Kowaljow and Rostagno, 2013). The lack of response from most of the edaphic variables evaluated in the treatments with branches, and branches with irrigation, could be attributed to the time since the application of treatments (10 months). This interval might not have been long enough to change the characteristics of the soils below the patches of branches. It has been found that the number of branches is an important variable to consider since, in the treatments with the heaviest cover of branches (2.7 kg of branches/m^2), the highest number of seedlings was recorded.

In another work carried out in the Monte Austral on 25 experimental units of severely degraded areas (abandoned petroleum locations after drilling) (Zuleta *et al.,* 2003), the average coverage of the vegetation with branches was five times greater (31%) when branches were used to cover the vegetation than on non-restored sites (6%), although there was a high variability between replicates in both cases. Seventy-six per cent of the registered individuals and 96% of the estimated plant cover corresponded to a single species: *Salsola kali* (Russian thistle). This is an exotic, opportunistic plant species considered a pest of agriculture, which indicates that this technique may have created appropriate microclimatic conditions for exotic 'pioneer' species.

Soil scarification: In places severely degraded by oil extraction activity, natural regeneration is promoted at large scales by ripping or scarification. This technique consists of the mechanical decompaction of soil conducted by a metallic bar with five angular hooks of 30 cm each approximately, separated 50 cm one from another. This structure is overlapped on the rear of a bulldozer. With this technique, based on mechanical top soil decompaction, both plant coverage and diversity increased after 13 years in the Monte Austral (Castro *et al.,* 2013). However, soil scarification provided benefits initially, but then its effects were insufficient to retain them unless it was accompanied by other interventions. Unfortunately, this technique has been applied indiscriminately by oil industries in Patagonia (IAPG 2009), in many cases with evident negative effects such as gullies of deep erosion on slopes. Instead, it is necessary to evaluate the benefits of deeper furrows as a technique and in smaller quantities than those produced by the current scarification and/or sinkholes according to any particular situation.

Complete reconstruction: In the complete reconstruction, all phases of recovery are characterized by manipulations of the biophysical environment. Projects, in this case, depend entirely on technical solutions (Clewell and Aronson, 2013). Two techniques in Patagonia were considered: direct seeding and plantation.

Direct seeding: Scarce knowledge on the germination and initial establishment of various species with potential for ecologically rehabilitating and restoring drylands in Argentina is one of the constraints to direct seeding. However, the number of germination studies with the purpose of dryland restoration is increasing in recent years (Rodriguez Araujo *et al.,* 2017).

Direct seeding in Patagonia was reported by Salomone (2013) in the restoration of pavements and control of sand dunes in Chubut where more than 6000 ha were successfully restored with *Leymus racemosus*. This is an exotic perennial grass species which was introduced from Eurasia. *Leymus racemosus* is very cold and drought resistant and it grows where annual precipitations are equal to or lower than 150 mm. It colonizes sandy, silty and clay soils and grows successfully in sand accumulations with low nutrient availability. In approximately five years after pioneering with *L. racemosus* the establishment of the native vegetation is likely to occur. Further, *L. racemosus* ends up or is almost absent from the plant community, which indicates that it is not at risk of becoming an invasive exotic plant. The use of exotic species must be evaluated in view of their risk of invasion (Zalba, 2013) and is generally not recommended in ecological restoration projects. Although it is suggested that the introduced species disappear by competition, it is likely that this model of intervention can be conducted using native species in the Patagonian steppes and other drylands of Argentina. The technological package developed (i.e., subsoiling, seed production, the spatial distribution of seeding in the field) can constitute (with native species) one of the more promising models for restoration based on direct seeding in drylands of Argentina.

In the same way, seeding with native grass species proved to be successful for the restoration of degraded areas in the arid Chaco (Quiroga *et al.*, 2009). They found high density of adult plants during the first two years after seeding. This was because of the almost exclusive establishment of *Paspalidium philippianum*. However, reductions of plant density were about 70-80% in all treatments, although differences due to seeding persisted in the third, dry year. Meanwhile, seeding of native grasses also showed promise for the productive, ecological rehabilitation of semi-arid environments of the Province of La Pampa (Chirino *et al.,* 2013). Various efforts on research in seedling establishment set the foundation of advancement in restoration based on seeding or complementing seeding with seedling plantations in drylands of Argentina. For example, Aguiar and Sala (1999) seeded *Bromus pictus*, to simulate grass establishment in the Patagonian steppe. These authors suggested that when shrubs are small, facilitation is more important than competition in the establishment of a dense pasture ring around shrubs.

In the Monte ecosystem, Bisigato and Bertiller (2004) reported that emergence in perennial grasses was more frequent at the southern/western patch-periphery than at other patch-periphery locations. However, seedling establishment of perennial grasses was homogeneously distributed throughout the patch periphery. Emergence under shrubs was more frequent at the center and periphery of patches than at inter-patch microsites. In contrast, established seedlings of shrubs were homogeneously distributed among microsites. Their results suggest that differential seedling establishment between life forms is the outcome of complex biotic and abiotic interactions and feedbacks at the patch level between seedlings and established plants. Both life forms appear to have a different role in the origin, dynamics and maintenance of spotting vegetation. Because of the ability to establish both at inter-patch and patch microsites, shrubs could be identified as colonizers or initiators of small plant patches in bare soil or they may contribute to increase the cover and size of pre-existing plant patches.

Both processes would be promoted in grazed areas.

Tree establishment in harsh environments such as seasonally dry forests has traditionally been described as being facilitated by existing shrubs and trees, which ameliorate harsh abiotic conditions; however, an alternative explanation postulates that facilitation is mediated by reduced herbivore damage, especially under shrubs (Torres and Renison, 2015). Seeding and planting experiments were established using two tree species (*Ruprechtia apetala* and *Schinopsis lorentzii*) in a full factorial design that included three vegetation types and two herbivore treatments at three sites (234 plots per species). It revealed that remnant woody vegetation patches were important for the effective establishment of the species studied on grazed sites, whereas effective establishment was feasible on woody patches on ungrazed sites in dry mountain forests (Torres and Renison, 2015).

The mechanization and streamlining of seed production, handling and treatment techniques to produce "restoration ready" seeds combined with the use of machinery designed for soil stabilization, microsite modification and precision seeding may present additional benefits to the restoration efficiency and long-term cost savings, in drylands in general (Kildisheva *et al.,* 2016) and in arid and semi-arid Patagonia in particular. Estimates of the establishment of seedlings from direct seeding without additional measures are low or very low (Kildisheva *et al.,* 2016; Ceccon *et al*., 2015; Grossnickle and Ivetić, 2017). However, before discarding the direct seeding on the basis of percentages of the establishment, it must be taken into account that the capacity to carry out the restoration is defined not only by the probability of success of the technique but also by the cost (James *et al.,* 2013).

Plantation of outplanting: Planting of seedlings has been the most traditional and recognized form of intervention to complete reconstruction of severely degraded areas in drylands of Patagonia (Dalmasso, 2010; Ciano, 2013).

In drylands of Argentina, direct transplanting of seedlings from the ecological regerences has been used with excellent results with Gramineae, Asteraceae and Cactaceae (Nittmann *et al.,* 2009; Farinaccio *et al.,* 2013; Gonnet *et al*., 2013; Dalmasso *et al.,* 2015). The success of survival and growth of several species (from nursery plants and direct transplanting) is very likely during wet growing cycles in the Monte Austral, although these moments when there is co-occurence of events favoring establishment are difficult to predict. Reported survival of the plantations was in general successful with the use of hydrogels and in the case of palatable species with protectors against herbivores (Pérez *et al*., 2010; Dalmasso, 2010; Ciano, 2013). Figures 1B, C and D shows various examples of the plantation of grasses and shrubs in Patagonia.

The best season for planting *Prosopis chilensis* and *Prosopis flexuosa* was at the end of the summer or beginning of fall when climatic conditions increased the probability of seedling survival (Catalán *et al*., 1994).

On the other hand, it is important to highlight the influence of plant ecophysiology in the performance of any species. A severe water stress reduced leaf expansion and production and dry matter production in *Senecio subulatus*. Therefore, when planning a revegetation with *S. subulatus*, these physiological responses to soil water content should be considered (Fernández *et al.,* 2015).

The influence of facilitating microorganisms is a topic where few studies have been carried out and possibly in the future, this subject might provide important contributions to the restoration of arid zones in Argentina (Álvarez and Pérez, 2018).

In relation to the use of ecological facilitation in plantations, the nursing effect of *Larrea divaricata* was assessed in relation to the establishment of two species of trees in arid Chaco (*P. chilensis* and *Aspidoserma quebracho-blanco*). The survival rate of *A. quebracho-blanco* was higher for those seedlings growing under the shrub canopy, showing a mutual relationship of facilitation (Barchuk and Díaz, 2000). In 'La Payunia' ecosystem of Patagonia González and Perez (2017) showed that *Senna arnottiana* and transplanting individuals of the grass species *Pappostipa speciosa* were able to survive in high percentages in isolation after transplanting; also, *P. speciosa* was a suitable species for promoting a higher shrub growth during the first critical years of recovery from the degraded, arid and semi-arid environments.

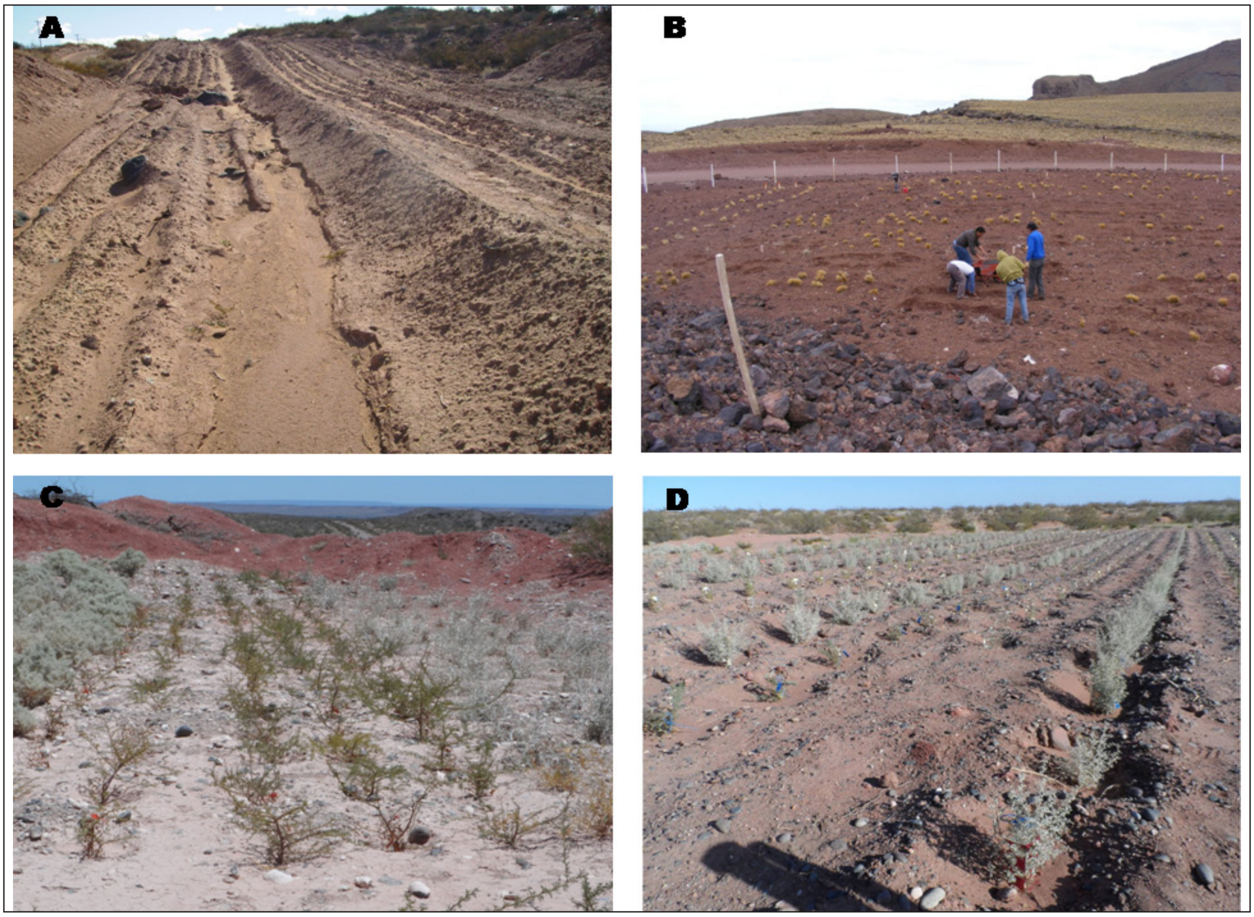

Fig. 1. Photographs depicting survival of plantations in the Monte Austral and Patagonia steppe (Neuquén Province). (A) Scarification on slopes can cause serious erosion problems; (B) Digging holes and planting Pappostipa speciosa; (C) Survival studies of Cercidium praecox (center), Atriplex lampa (left) and Hyalis argentea var. Latisquama (right) after two years in Monte Austral; (D) Survival studies of Atriplex lampa in the Monte Austral after one year. Credits of B, C and D: Daniel Pérez and Fernando Farinaccio (LARREA).

Finally, in relation to the purpose of restoring for productive purposes, native perennials had been proposed as suitable candidates. This is because they improve the supply of goods and services and secondary metabolites, such as special oils, resins, rubber, gums, bioenergy, etc. (González Paelo *et al.,* 2015). These authors identified some traits that might affect the supply of ecosystem services (e.g., soil fertility, nutrient cycling and hydrological control).

On the other hand, Guevara *et al*. (2009) reported successful results in biomass and protein production on native and exotic shrub and grass species for the rehabilitation of drylands of Argentina. These species included for example *Atriplex nummularia,* originally from Australia. The restoration with desirable species for livestock production seems to be essential for the general sustainability of drylands agroecosystems in Argentina. This last mentioned perspective includes the consideration of the risk of introduction of exotic species and of genetic aspects of the germplasm. As mentioned in the case of branching, consideration of invasive species and the biophysical component are essential in the rehabilitation and restoration of degraded areas (Aguiar and Roman, 2007; Clewell and Aronson, 2013).

A new and promising proposal called "Dryland Framework Species Approach" (Pérez *et al.,* 2019) formulates criteria and recommendations to increase the scale for the plantations in restoration processes. This requires an evaluation of candidate species for planting which must have: (a) ease of germination: (b) a high seedling survival and rapid growth rates and (c) attractiveness for the fauna. In addition, the following concerns are necessary of consideration: i) species selection,

ii) local knowledge, iii) differing spatial layouts, iv) efficient monitoring for adaptive management and v) creation of microsites for seeds both near and far from planting sites. This approach can be integrated with pre-existing models and techniques, e.g., state and transition modelling, landscape functional analysis, spatial analysis and predictive-system-models that capture the probabilistic nature of ecosystem response to management practices and rehabilitation and restoration interventions (Tongway and Ludwig, 2011; Squires, 2016).

Decision-making in Restoring Arid Zones of Patagonia: Social Concerns

It is important to emphasise that restoration is an interdisciplinary or even more, a transdisciplinary discipline (Clewell and Aronson, 2013). This implies that it needs to address human, social, political, legal and educational issues. In Patagonia, a model of a participatory approach to address restoration in arid environments has been the Socio-Productive Environmental Units (USPAS) (Pérez and Farinaccio, 2013). This approach implemented on a pilot scale in severely degraded areas implies the formulation of joint working plans between three components: Municipalities or local development commissions, local producers (livestock or equivalent) and schools. In this way, most of the spectrum of social actors will be able to define actions and indicators of achievement. Likewise, ecological restoration based on environmental education has been proposed. This is to progressively achieve cultural goals for ecological literacy (Pérez *et al.*, 2017). In relation to legal frameworks, it is necessary to homogenize requirements for restoration in the different provinces of Argentina and on different activities (Pérez *et al.*, 2018).

The economy plays a central role in ecological restoration (Clewell and Aronson, 2013). The innovation with new techniques, changes in certain procedures (e.g., the indiscriminate application of scarification) and cost calculations can reduce the cost or make it more efficient.

Conclusion

The restoration of drylands is an emerging theme where studies have been made recently in Argentina and in drylands of Patagonia in particular (Pérez *et al.*, 2018). A wide range of intervention options have been initiated in the region, involving different scales, levels of efforts and costs (Fig. 2).

These in-depth investigations and systematized practices will allow development of knowledge not yet available for decision making. However, it is possible to glimpse interesting patterns, promising species, conceptual frameworks, and increasing ecological and physiological knowledge that already constitute the basis for practitioners and decision making in restoration. A change in the society's relationships with the arid and semi-arid nature of drylands is necessary. These are great challenges that dryland regions should face.

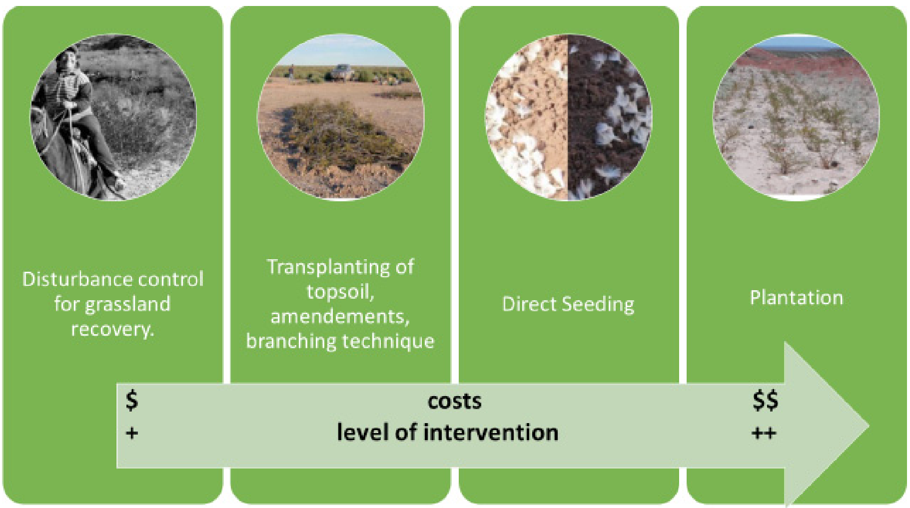

Fig. 2. Costs and levels of intervention involved in the restoration and rehabilitation of degraded areas in drylands of Argentina.

Acknowledgments

We acknowledge financial support to Research Project 04-U014. We are also grateful to the Foundation for the Regional Development of the Universidad Nacional del Comahue because of its support on the financialprojects of LARREA.

References

Abella, S.R. 2010. Disturbance and plant succession in the Mojave and Sonoran Deserts of the American Southwest. *International Journal of Environmental Research and Public Health* 7: 1248-1284.

Aguiar, M.R. and Román, M.E. 2007. Restoring forage grass to support the pastoral economy of arid Patagonia. In *Restoring Natural Capital: Science, Business and Practice* (Eds. J. Aronson, S.J. Milton and J.N. Blignaut), pp. 112-121. Island Press, Washington. 400 p.

Aguiar, M.R. and Sala, O.E. 1999. Patch structure, dynamics and implications for the functioning of arid ecosystems. *Trends in Ecology and Evolution* 14: 273-277.

Álvarez, A.S. and Pérez, D.R. 2018. Microbial inoculation of *Parkinsonia praecox* (Ruiz & Pav. ex Hook.) Hawkins for ecological restoration". *Phyton, International Journal of Experimental Botany* 87: 274-279.

Barchuk, A.H. and Díaz, M.P. 2000. Vigor de crecimiento y supervivencia de plantaciones de *Aspidosperma quebracho-blanco* y de *Prosopis chilensis* en el Chaco árido. *Quebracho* 8: 17-29.

Bisigato, A.J. and Bertiller, M.B. 1997. Grazing effects on patchy dryland vegetation in northern Patagonia. *Journal* of *Arid Environments* 36: 639-653.

Bisigato, A. and Bertiller, M. 2004. Seedling recruitment of perennial grasses in degraded areas of the Patagonian Monte. *Journal of Range Management* 57: 191-196.

Bonvissuto, G.L. 2008. Guía de Condición para Pastizales Naturales de Precordillera, Sierras y Mesetas y Monte Austral de Patagonia. S.C. de Bariloche., Centro Regional Patagonia Norte, INTA.

Briske, D.D., Fuhlendorf, S.D. and Smeins, F.E. 2005. State-and-Transition models, thresholds and rangeland health: A synthesis of ecological concepts and perspectives. *Rangeland Ecology and Management* 58: 1-10.

Busso, C.A. and Bonvissuto, G.L. 2009. Structure of vegetation patches in northwestern Patagonia, Argentina. *Biodiversity and Conservation* 18: 3017-3041.

Castro, M.L., Zuleta, G., Pérez, A.A., Ciancio, M.E., Tchilinguirian, P. and Escartín, C.A. 2013. Rehabilitación de estepas arbustivas en locaciones petroleras del Monte Austral. Evaluación de la técnica de escarificado. I: vegetación. In *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. D.R. Pérez, A.E. Rovere and M.E. Rodriguez Araujo), pp. 213-224. Vázquez Mazzini, Buenos Aires, 518 p.

Catalán, L., Carranza, C., Gonzáles, L., Karlin, U. and Ledesma, M. 1994. Afforestation trials with *Prosopis chilensis* (Mol.) Stuntz and *Prosopis flexuosa* D.C. in the Dry Chaco, Argentina. *Rangeland Ecology and Management* 70: 113-119.

Ceccon, E., González, E.J. and Martorell, C. 2015. Is direct seeding a biologically viable strategy for restoring forest ecosystems? Evidences from a Meta-analysis. *Land Degradation and Development* 27: 511-520.

Chirino, C.C., Suarez, C. and Morici, E. 2013. Propuesta metodológica de rehabilitación de un arbustal en la zona árida de la provincia de La Pampa. In *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. D.R. Pérez, A.E. Rovere and M.E. Rodriguez Araujo), pp. 360-368. Vázquez Mazzini, Buenos Aires, 518 p.

Ciano, N. 2013. Rehabilitación de áreas degradadas por la actividad petrolera. In *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. D.R. Pérez, A.E. Rovere and M.E. Rodriguez Araujo), pp. 261-274. Vázquez Mazzini, Buenos Aires, 518 p.

Clewell, A.F. and Aronson, J. 2013. Ecological restoration. Principles, values and structures of an emerging profession. Second edition. Island Press, Washington, DC, USA. http://dx.doi.org/10.5822/978-1-59726-323-8

Dalmasso, A.D. 2010. Revegetación de áreas degradadas con especies nativas. *Boletín de la Sociedad Argentina de Botánica* 45: 149-171.

Dalmasso, A.D., Quattrocchi, G. and Azcurra C. 2015. Revegetación de taludes viales en la Ruta Nacional 7, Santa Rosa, Mendoza.In *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. E. Martínez Carretero and A.D. Dalmasso), pp. 309-326. The author (CD-ROM), Mendoza. 483 p.

Distel, R.A. 2016. Grazing ecology and the conservation of the Caldenal rangelands, Argentina. *Journal of Arid Environments* 134: 49-55.

Farinaccio, F., Rovere, A. and Pérez, D. 2013. Rehabilitación con *Pappostipa speciosa* (Poaceae), en canteras abandonadas por actividad petrolera en zonas áridas de Neuquén, Argentina. In: *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. D.R. Pérez, A.E. Rovere and M.E. Rodriguez Araujo), pp. 308-319. Vázquez Mazzini, Buenos Aires, 518 p.

Fernández, M.E., Cony, M.A. and Passera, C.B. 2015. Respuestas fisiológicas de plantines de *Senecio subulatus* a diferentes niveles de suministro de agua. In: *Restauración ecológica en la Diagonal Árida de la Argentina* (Eds. E. Martínez Carretero and A.D. Dalmasso), pp. 233-241. The author (CD-ROM), Mendoza. 483 p.

Friedel, M.H. 1991. Range condition assessment and the concept of thresholds: A viewpoint. *Journal of Range Management* 44(5): 422-426.

Golluscio, R.A., Deregibus V.A. and Paruelo J.M. 1998. Sustainability and range management in the Patagonian steppes. *Ecología Austral* 8: 265-284.

Golos, P.J., Dixon, K.W. and Erickson, T.E. 2016. Plant recruitment from the soil seed bank depends on topsoil stockpile age, height and storage history in an arid environment. *Restoration Ecology* 24: 553-561.

Gonnet, J.M., Pastor, L., Boaglio, G., Gudiño, G., Dansey, J.M. and Castro Videla, M. 2013. Recuperación de cactáceas en un desmonte de matorral del piedemonte semiárido de Mendoza, Argentina. In *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. D.R. Pérez, A.E. Rovere and M.E. Rodriguez Araujo), pp. 369-376. Vázquez Mazzini, Buenos Aires, 518 p.

González, F.M. and Pérez, D.R. 2017. Contributions of ecological facilitation for restoring environments with high conservation value in the Argentine Patagonia. *Phyton, International Journal of Experimental Botany* 86: 332-339.

González-Paleo, L., Pastor-Pastor, A., Vilela, A.E. and Ravetta, D.A. 2015. Utilización de cultivos perennes en rehabilitación: ¿qué criterios ecofisiológicos deben ser utilizados para guiar la selección? In *Restauración ecológica en la Diagonal Árida de la Argentina* (Eds. E. Martínez Carretero and A.D. Dalmasso), pp. 61-74. The author (CD-ROM), Mendoza. 483 p.

Grossnickle, S.C. and Ivetić, V, 2017. Direct Seeding in Reforestation – A Field Performance Review. *Reforesta* 4: 94-142.

DOI: https://dx.doi.org/10.21750/REFOR.4.07.46

Guevara, J.C., Grünwaldt, E.G., Estevez, O.R., Bisigato, A.J., Blanco, L.J., Biurrun, F.N., Ferrando, C.A., Chirino, C.C., Morici, E., Fernández, B., Allegretti, L.I. and Passera, C.B. 2009. Range and livestock production in the Monte Desert, Argentina. *Journal of Arid Environments* 73: 228-237.

IAPG 2009. Consideraciones ambientales para la construcción de locaciones y lagestión de lodos y recortes durante la Perforación de Pozos. www.iapg.org.ar/sectores/practicas/practicas.htm. Accessed 30/4/2018.

James, J.J., Sheley, R.L., Erickson, T., Rollins, K.S., Taylor, M.H. and Dixon, K.W. 2013. A systems approach to restoring degraded drylands. *Journal of Applied Ecology* 50: 730-739.

Kildisheva, O.A., Erickson, T.E., Merritt, D.J. and Dixon, K.W. 2016. Setting the scene for dryland recovery: an overview and key findings from a workshop targeting seed-based restoration. *Restoration Ecology* 24: 36-42.

Kowaljow, E. and Mazzarino, M.J. 2007. Restoration in semi-arid Patagonia: Chemical and Biological response to different compost quality. *Soil Biology and Biochemistry* 39: 1580-1588.

Kowaljow, E. and Rostagno, C.M. 2013. Enramado y riego como alternativas de rehabilitación de regions semiáridas afectadaspor el tendido de ductos. Ecología Austral 23: 62-69.

López, D.R., Brizuela, M.A., Willems, P., Aguiar, M.R., Siffredi, G. and Bran, D. 2013. Linking ecosystem resistance, resilience and stability in steppes of North Patagonia. *Ecological Indicators* 24: 1-11.

Massara Paletto, V., Beider, A., Buono, G. and Ciano, N. 2013. Banco de semillas y su relación con la revegetación natural en taludes. In *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. D.R. Pérez, A.E. Rovere and M.E. Rodriguez Araujo), pp. 336-343. Vázquez Mazzini, Buenos Aires, 518 p

Mazzoni, E. and Vazquez, M. 2009. Desertification in Patagonia. In *Geomorphology of Natural and Human-induced Disasters in South America* (Ed. E. In Latrubesse), pp. 351-377. Developments in Earth surface processes. Elsevier.

Nittmann, J.J., Pérez, D., Rovere, A. and Farinaccio, F. 2009. Ensayos de Rehabilitación de canteras degradadas a partir de transplante directo en la Provincia de Neuquén (Argentina). Congreso Iberoamericano y del Caribe sobre restauración Ecológica. Curitiba, Brasil.

Pérez, D.R. and Farinaccio, F.M. 2013. La unidad socio productivo ambiental: un modeloposible para la restauración de ecosistemas áridosdegradados. In *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. D.R. Pérez, A.E. Rovere and M.E. Rodriguez Araujo), pp. 422-439. Vázquez Mazzini, Buenos Aires, 518 p.

Pérez, D., Meli, P., Renison, D., Barri F., Beider, A., Burgueño, G., Dalmasso, A., Dardanelli, S., de Paz, M., Farinaccio, F., Papazian, G., Sirombra, M. and Torres, R. 2018. La Red de Restauración Ecológica de la Argentina (REA): Avances, vacíos y rumbo a seguir. *Ecología Austral* 28: 353-360.

Pérez, D.R., Rovere, A.E. and Farinaccio F.M. 2010. Rehabilitación en el desierto: Ensayos con plantas nativas en Aguada Pichana, Neuquén, Patagonia. Vázquez Mazzini Editores. 80 p.

Pérez, D.R., Farinaccio, F. and Aronson, J. 2019. Towards a Dryland Framework Species Approach. Research in progress in the Monte Austral of Argentina. *Journal of Arid Environments*. doi.org/10.1016/j.jaridenv.2018.09.01

Quiroga, E., Blanco, L. and Orionte, E. 2009. Evaluación de estrategias de rehabilitación de pastizales áridos. *Ecología Austral* 19: 107-117.

Reynolds, J.F., Smith, D.M.S., Lambin, E.F., Turner, B.L., Mortimore, M., Batterbury, S.P., Downing, T.E., Dowlatabadi, H., Fernández, R.J., Herrick, J.E., Huber-Sannwald, E., Jiang, H., Leemans, R., Lynam, T., Maestre, F.T., Ayarza, M. and Huber-Sannwald, E. 2007. Global desertification: Building a science for dryland development. *Science* 316: 847-851.

Rodriguez Araujo, M.E., Pérez, D.R. and Bonvissuto, G.L. 2017. Seed germination of five Prosopis shrub species (Fabaceae-Mimosoideae) from the Monte and Patagonia phytogeographic provinces of Argentina. *Journal of Arid Environment* 147: 159-162.

Rueter, B.L. and Rodriguez, F.J. 2013. Restauración natural en picadas petroleras en dosdistritos de la provincia fitogeográfica patagónica. In *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. D.R. Pérez, A.E. Rovere and M.E. Rodriguez Araujo), pp. 351-358. Vázquez Mazzini, Buenos Aires, 518 p.

Salomone, J.M. 2013. Deterioro de tierras y estabilización de médanos en la provincia de Chubut. In *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. D.R. Pérez, A.E. Rovere and M.E. Rodriguez Araujo), pp. 377-389. Vázquez Mazzini, Buenos Aires, 518 p.

Squires, V.R. 2016. *Ecological Restoration: Global challenges, Sociological aspects and Environmental Benefits*. NOVA Science Publishers, N.Y. 309 p.

Tongway, D.J. and Ludwig, J.A. 1996. Rehabilitation of semi-arid landscapes in Australia. I. Restoring productive soil patches. *Restoration Ecology* 4: 388-397.

Tongway, D.J. and Ludwig, J.A. 2011. *Restoring Disturbed Landscapes: Putting Principles into Practice*. Island Press, Washington, DC.

Torres, R.C. and Renison, D. 2015. Effects of vegetation and herbivores on the regeneration of two tree species in a seasonally dry forest. *Journal of Arid Environments* 121: 59-66.

UNCCD 1994. United Nations Convention to Combat Desertification, Intergovernmental Negotiating Committee for a Convention to Combat Desertification, Elaboration of an International Convention to Combat Desertification in Countries Experiencing Serious Drought and/ or Desertification, Particularly in Africa. United Nations, New York, USA. 6 pp.

Zalba, S.M. 2013. Incorporando el desafío de las invasiones biológicas a los proyectos de restauración ecológica. In *Restauración Ecológica en la Diagonal Árida de la Argentina* (Eds. D.R. Pérez, A.E. Rovere and M.E. Rodriguez Araujo), pp. 61-72. Vázquez Mazzini, Buenos Aires, 518 p.

Zuleta, G.A., Reichmann, L.G., Li Puma, M.C., Fernández, A., Bustamante Leiva, A.D. and Tchilinguirián, P. 2003. Ecología de disturbios y restauración de estepas arbustivas del monte austral en explanadas abandonadas de la cuenca neuquina Conference: II Congreso de Hidrocarburos (29 junio - 2 de julio). Instituto Argentino del Petróleo y del Gas (IAPG) - Buenos Aires.

Printed in December 2018