Revista Chilena de Historia Natural
66: 291-303, 1993

Rehabilitation of degraded ecosystems in central Chile and its relevance to the arid "Norte Chico"

Rehabilitación de ecosistemas degradados de Chile central y su relevancia para el "Norte Chico" árido

CARLOS OVALLE[1], JAMES ARONSON[2], JULIA AVENDAÑO[3], RAUL MENESES[4] and RAUL MORENO[5]

[1]Estación Experimental Quilamapu, INIA. Casilla 426, Chillán, Chile.
[2]Centre L. Emberger, C.N.R.S., B.P. 5051 - 34033 Montpellier, France. [3]Estación Experimental Cauquenes, INIA. Casilla 165, Cauquenes, Chile. [4]Estación Experimental Los Vilos, INIA. Los Vilos, Chile.
[5]Facultad de Ciencias, Universidad de La Serena. Casilla 599, La Serena, Chile.

ABSTRACT

An ecosystem rehabilitation project in the subhumid 7th Region of central Chile is described, with a three-tiered research and development (R & D) approach that addresses the structure and functioning of soils and vegetation and aims, in the long-term, at a fullscale transformation of the region into a mosaic of agroforestry systems and natural ecosystem reserves. The important role of native and carefully-screened exotic nitrogen-fixing legumes in "jumpstarting" the rehabilitation process is underlined. We then suggest that a similar R & D approach could be applied in the arid "Norte Chico" region of northern Chile as well. Apart from immediate interventions, emphasis is placed on revised management of land and water, flora and fauna through the replacement of "artificial negative selection" by a strategy of "positive selection". Also noted are the numerous gaps in current knowledge and the grinding socio-economic realities that hinder any rapid realization of our optimistic scenario.

Key words: Ecological rehabilitation, arid and semiarid land ecosystems, nitrogen-fixing legumes, bioresources, artificial negative selection, positive selection, Chile.

RESUMEN

Se describe un proyecto sobre rehabilitación ecológica en la región subhúmeda de Chile central. El énfasis ha sido puesto en el mejoramiento de la fertilidad de los suelos, inducido por las leguminosas leñosas y herbáceas nativas y por la introducción de plantas exóticas fijadoras multipropósito, cuidadosamente seleccionadas por su mayor eficiencia de fijación y aportes a la producción de fitomasa. Se sugiere que un programa similar podría ser válido para la región árida (Norte Chico) del país. Además de algunas intervenciones inmediatas y a largo plazo se propone una revisión de sistemas de manejo de suelos, agua, flora y fauna utilizando una estrategia de "selección positiva" en vez de la "selección artificial negativa" que domina actualmente. Asimismo se mencionan la falta de conocimiento en numerosos aspectos del manejo de los recursos naturales renovables y los obstáculos socioeconómicos que impiden la actualización rápida de nuestro escenario optimista.

Palabras claves: Rehabilitación ecológica, ecosistemas áridos y semiáridos, leguminosas fijadores de nitrógeno, recursos biológicos, selección artificial negativa, selección positiva.

INTRODUCTION

In the arid, semiarid and subhumid regions of central and northern Chile, virtually all terrestrial ecosystems have been disturbed and degraded (Muñoz Schick 1975, Bonilla 1977, Bahre 1979, Gastó 1979, Balduzzi *et al.* 1981, Fuentes & Hajek 1978, 1979, Fuentes & Prenafeta 1988, Etienne *et al.* 1983, 1987, Armesto & Pickett 1985, Gastó *et al.* 1990) to the point that a full restoration of their structure and function to a presumed original state is probably no longer feasible (Sprugel 1991). Nevertheless, ecological rehabilitation that takes indigenous ecosystems and landscapes as working models, but emphasize functionality and productivity over regaining former species inventories appears a promising strategy to fight continued desertization and rural poverty. Rehabilitation and restoration have in common the fact that they take indegenous ecosystems as their model (Fig. 1) while the more common land use which we call "reallocation" assigns new use(s) to a site

(Received 13 july 1992; accepted 16 November 1992.)

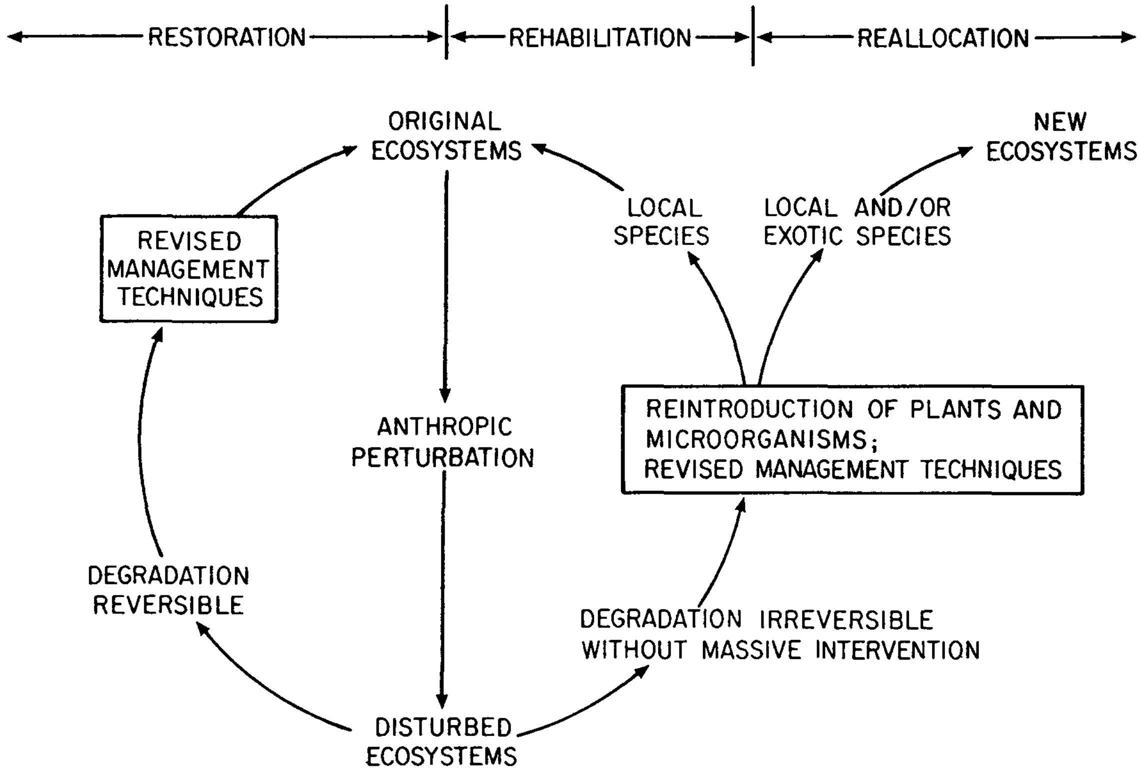

Fig. 1: Schematic representation of ecosystem degradation and alternative responses of restoration, rehabilitation or reallocation.

Modelo esquemático de la degradación de ecosistemas y de las respuestas alternativas de restauración, rehabilitación o realocación.

that does not necessarily bear any relationship to the indigenous ecosystem's structure or functioning (Aronson *et al.* 1993).

In this article, we describe an ongoing rehabilitation project in the subhumid portion of the mediterranean-type climate zone of central Chile, and discuss its possible relevance to part of the arid region of northern Chile, the "Norte Chico". Given the far less developed agricultural infrastructure in the Norte Chico, and the need to develop new crops and new approachs, we also highlight the numerous underexploited and, above all, ill-managed plant and animal resources of the Chilean arid zone.

Current status of the espinales

Over 2,000,000 ha in the subhumid portions of the "secano interior", i.e., the unirrigated portions of the Central depression of central Chile, are dominated by a synanthropic formation consisting of the nitrogen-fixing legume tree *Acacia caven* Mol. (Fabaceae: Mimosoideae) and a large variety of native and exotic annuals (Ovalle *et al.* 1988, 1990). The resulting pseudo-savannas (locally known as "espinales") provide the framework for agriculture and animal husbandry for ca. 300,000 people in the area between Santiago and Chillán. Although receiving 350-700 mm mean annual precipitation, this area is functionally arid because annual rainfall is highly variable in amount and efficiency and is concentrated in the coldest months of the year. Primary productivity and succession is also severely inhibited by chronic disturbance and lack of regeneration of most perennial species.

It has been estimated that only about 25% of the espinales in the 7th and 8th Regions, and about 30-35% in the 5th and 6th Regions, possess and adequate tree stratum to allow for gradual improvement through the revision of management techniques alone (Ovalle *et al.* 1988, 1991). In a cartographic study (Ovalle *et al.*, in review b) carried out on 23,000 ha near Cauquenes, in the 7th Region, only 2% of the study area could be classified as having espinales in "very good" condition on the basis of tree density and height. Fully 44% of the remaining espinales were classified as degraded or very degraded. Only 5% of the study area had remnants of native matorral, and these were all badly degraded. (The rest of the study area has been reallocated to rainfed cerealculture or vineyards wherein all trees are systematically removed.)

Apart from the nature of their arboreal stratum, the productivity and biodiversity of the espinales is blocked by the condition of their soils. Most espinal soils are so badly degraded, depleted and compacted that they represent a serious limitation to water infiltration, nutrient cycling and plant growth, even for *Acacia caven*. Current plant and animal production levels in the espinales are consequently very low as compared to that of other mediterranean-type climate areas with similar rainfall regimes (Serrano & Jara 1975, Crespo 1985, Ovalle *et al.* 1990, cf. Whitford 1986, 1988).

Espinal research program

Well-adjusted livestock management techniques can, of course, improve productivity in central Chilean espinales, independently of direct manipulations of soils or vegetation. For example, when animal stocking rates were re-adjusted in accordance with annual fluctuations in primary productivity in a well-managed espinal near Cauquenes, both pasture and animal yields increased dramatically (Ovalle 1986, Ovalle & Avendaño 1987). A significant increase in ecosystem yield to the farmer was thus achieved through the simple revision of management techniques (Avendaño *et al.* 1990, 1992).

Over and above livestock management techniques, however, our research and development (R & D) program addresses soil and vegetation rehabilitation directly. The major tool being tested for this is the experimental introduction of a variety of N_2-fixing plant/microorganism "couples" in representative sites from Cauquenes, in the subhumid zone, to Quebrada El Tangue, near La Serena (4th region), in arid zone (Fig. 2). We hypothesize that the introduction of compatible and appropriate woody and herbaceous legume/N_2-fixing microsymbiont "couples" to espinales can increase the amount of total and available nitrogen, and beneficial microflora and fauna, in shallow and deep soils, increase water infiltration to deep soil layers, and promote the establishment and development of other plants of all types (Ovalle *et al.* 1990, 1991, in press, in review a).

Thorough revision of water use and resource management techniques will also be required to keep the rehabilitation process moving and to achieve a tightening of nutrient cycles such as generally characterizes mature, stable ecosystems (Odum 1969, Vitousek & Reiners 1975). Yet given the crucial role of people in the rehabilitation process, we believe that demonstrating the great diversity of native and non-native but well-adapted bioresources available is the first step to achieving social and economic change. At the same time, however, the potentially dangerous consequences of the intentional introduction of fast-growing woody plants and their associated microorganism must be carefully monitored so as to avoid the inadvertant introduction of yet more exotic weeds.

To obtain farmers' interest and willingness to cooperate, we describe our program in three stages. First, in the short term, we seek ways and means to manage existing plant resources for maximum productivity. This primarily takes the form of revised management of espino, the dominant species of Chilean espinales. However, the introduction of selected lines of the well-known annual legume, "hualputra" (*Medicago polymorpha*), with selected strains of rhizobia (Del Pozo *et al.* 1989a, b, c, Herrera *et al.* in review) should also be rapidly assimilable by local farmers. If we can demonstrate that local ecotypes of this annual medic increase wheat yields in a crop rotation, many farmers are likely to adopt them just as they have in other arid or semiarid mediterranean climate regions (Puckridge & French 1983, Chatterton & Chatterton 1984, Crespo 1985).

Second, in the mid-term (5-10 years), we propose that introducing N_2-fixing fodder shrubs such as tagasaste (*Chamaecytisus proliferus* subsp. *palmensis*), from the Canary Islands (Snook 1982, Ovalle *et al.* 1990, in press), can help create a "mixed espinal" of greater productivity and stability than the

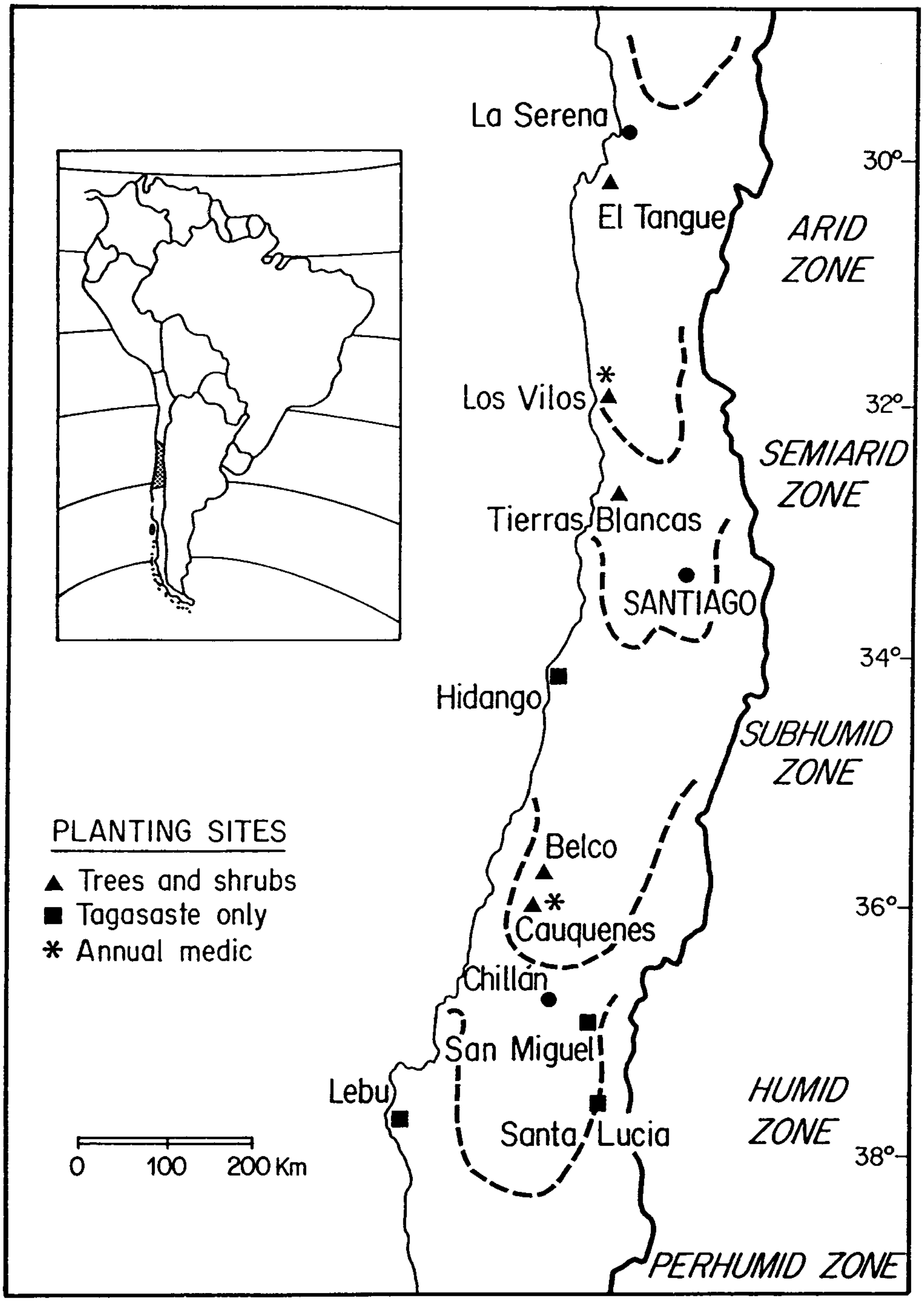

Fig. 2: Sites of main experimental plantations in central Chile.

Sitios de las plantaciones experimentales principales en Chile central.

monospecific espinal currently found in central Chile (Ovalle *et al.* 1990, 1991).

Long-term (10-25 years), we envision the incorporation of long-lived, prolific cultivars of espino and algarrobo (*Prosopis* spp.) as well as other multipurpose trees and shrubs from the Chilean matorral or other lands. Current trials include 10 Chilean and non-Chilean provenances of *Acacia caven* (espino), several Argentinian and Chilean provenances of *Prosopis alba, P. chilensis* and other algarrobos, the native fodder trees belloto (*Beil-*

schmedia spp.) and maitén (*Maytenus boaria*) (Ovalle *et al.* in review a, b, in press). Even more than shrubs or annuals, it is these large, deep-rooted trees that can do the most to rehabilitate soils in a profound and long-lasting way.

Many stages of R & D are thus envisioned for vegetation and soil rehabilitation. Hopefully, greater diversification of livestock herds will take place as well as enriched soils and plant communities, as local people assume the role of agro-ecosystem manager of "mixed" espinales. Incorporation of these new plant species into existing land use systems will, of course, require considerable rural extension work. Even so, this scenario may seem overly optimistic, but we see no other alternative to continued degradation in the depressed "secano interior". Moreover, we propose that a similar R & D approach could be applied, with certain modifications, in northern Chile as well.

Current status of the 'Norte Chico'

From La Serena north, the coastal and inland valley desert flora of Chile belongs to a biogeographic region that extends all the way to the Peru-Ecuador border (Rauh 1985, Rundel *et al.* 1991). This vast region is divided between the "Norte Chico" (the area lying north of the La Ligua-Petorca line to just south of Chañaral and the Norte Grande (Chañaral to the Peruvian border) (Muñoz Schick 1985). Unlike many desert areas, the hyperaridity of the Atacama and southern Peruvian deserts appears to date back to the Middle Miocene or late Eocene (Rundel *et al.* 1991).

Historical records indicate that the vallies of both the Río Huasco and Río Copiapó once supported dense stands of phreatophytic trees. Indeed, Copiapó was once known as San Francisco de la Selva because of the extensive stands of trees which covered the valley (Klohn 1972, cited in Rundel *et al.* 1991). However, throughout the area, people (and mining companies) have dramatically reduced woody vegetation cover and lowered watertables (Lloyd 1976). Given the degradation which has taken place, it appears unlikely that full restoration of indigenous ecosystems could be achieved without massive inputs of energy and capital. On the other hand, little, further development of conventional irrigated crops, even in favored river vallies such as the Copiapó, seem feasible. New approaches are needed if sustainable development has to proceed.

In the mid-1970s, no less than 52% of the ca. 3.5 million ha of the 4th Region was used for rainfed agriculture of livestock husbandry, and 3% was under irrigated agriculture. Of the remaining, fully 44%, or 1.57 million ha, were considered "sterile", and of no use whatsoever (INE 1976, cited in Azócar & Lailhacar 1990). This latter statistic refers primarily to former rangelands rendered useless through overcutting and overgrazing, and neglects the possibilities of ecological rehabilitation. In a detailed study carried out on 300,000 ha in the 4th Region, 59% of the area studied was found "extremely" degraded (Etienne *et al.* 1978). In the last 15 years the situation has only gotten worse. Althought a number of basic and applied ecological studies have been carried out in the 4th and 5th regions (Bonilla *et al.* 1977, Cosio & Demanet 1984, Azócar & Lailhacar 1990, Gastó *et al.* 1990), desertization and ecosystem degradation persist (Fuentes & Hajek 1978, 1979, Etienne *et al.* 1982, 1983, 1987, D'Herbes 1988). Less than 0.1% of the 18 million hectares of the Norte Chico are currently cultivated, and unrestained grazing and fuelwood harvesting continue to be the major activities throughout the remainder of the area.

Saltbush (*Atriplex* spp.) plantations (Olivares & Gastó 1981, Lailhacar *et al.* 1981) and limited reforestation in the Pampa del Tamarugal (Habit 1981) are just about all that has been attemped in the way of agro-ecological rehabilitation or restoration in northern Chile. Results of these endeavors are only partially satisfactory.

Research proposals for the Norte Chico

In our opinion, a similar R & D program to that we are pursuing in central Chile could be developed in the Norte Chico. The four essential features are: 1) the use of indigenous ecosystems as models for sustainable development, 2) rehabilitation of degraded soils, 3) the development of full potential of native plants and animals and 4) the use of a three-tiered approach to maintain local farmers' and pastoralists' interest during early stages.

As a result of aridity, ecosystems in the Norte Chico are probably less disturbed and natural resources overall less depleted than those of central Chile. Prospects for their rehabilitation may in fact be greater in the long run. Most native plants and animals are still present, and many of these show very high economic value (Rodríguez *et al.* 1984, Muñoz Schick 1985, Aronson 1990). It must be emphasized that without substantial subsidies (energy, water and capital), the rehabilitation process will be slow in the arid Norte Chico. Yet the potential role of native nitrogen-fixing "couples", and of mechanical emendations to soil surfaces in the speeding up the process should not be underestimated.

As mentioned, northern Chile boasts many valuable natural products, including animal and vegetable as well as the better-known mineral resources. Yet very few of the faunal and floral riches are incorporated into existing production systems nor even considered as potential resources in current R & D programs. Some of these need to be developed rapidly so as to show local people the possibility of alternative strategies for gaining a livelihood. Finally, mechanical interventions to improve soil fertility and to reduce or channel surface run-off during rain events should be attempted while alternative water sources should also be developed. For example, reactivation of the physical and hydrological functioning of degraded vertisols in northern Cameroon has been achieved by interventions such as "pitting", plowing in of annual grasses, and the creation of 50-200 m^2 water-catchment basins that force water to infiltrate more or less evenly (Masse 1992, Aronson *et al.* in review a). Nevertheless, the critical obstacle is perhaps a matter of attitude about the use of biological resources.

"Artificial negative selection" (Burkart 1976, Aronson 1990, Aronson *et al.* in review b) refers to the nearly universal process whereby most people (and animals) exploit plants and animals in reverse order to that which would be in their own longterm interest. Instead of preserving the "elite" individuals of wild populations they exploit –which practise is called "positive selection"– most people systematically remove first the largest, most valuable and most palatable trees, shrubs and grasses (and animals), the next best next, and the worst last. Artificial negative selection is the leading, anthropogenic cause of genetic erosion at or below the species level. When its consequences are evaluated at higher levels, negative selection can be seen to accelerate rural exodus while it contributes to the degradation of ecosystems and fragmentation of landscapes. We will now attempt to elucidate all of these points by the use of stylized "before" and "after" drawings (Figs. 3, 4).

Figure 3 gives a stylized image of a small village of the arid Norte Chico, well away from the big centers of current development in the major river vallies (the Copiapó, Huasco, Elqui, Limarí and Choapa). Apart from individually owned agricultural plots, livestock –mostly goats– are pastured on communally owned lands. The crevised, eroded soils are the result of badly managed water sources, and the fact that much of what fresh water exists upstream is diverted for mining and urban centers elsewhere. Fig. 3 also shows that many formerly cultivated fields have been abandoned. Native fauna and flora outside of cultivated areas are also impoverished in this depressing landscape, due to uncontrolled hunting, trapping and ill -managed grazing by goats– all examples of artificial negative selection.

The principal product, goat's milk, is of very poor quality. The empty corral and the absence of animals near the village suggest that even goats must wander far afield to find pasture, just as the villagers themselves must travel further and further every week to find firewood for cooking and heating their homes. Furthermore, no infraestructure exists for improving the quality of the goat's milk produced. The village gets smaller each year as young people leave the area, looking for work in mines and the cities, or else to the rapidly developing agricultural centers in the irrigable river vallies. There seems little hope for reversing current ecological and socio-economic trends.

In Figure 4, however, we see the same village and surrounding landscape as it could appear in the future. Offstage, the permanent river valleys that cross the arid region continue to have the highest concentration of people and export-based agriculture in the region. However, rational watershed management at the village and landscape level, plus improvi-

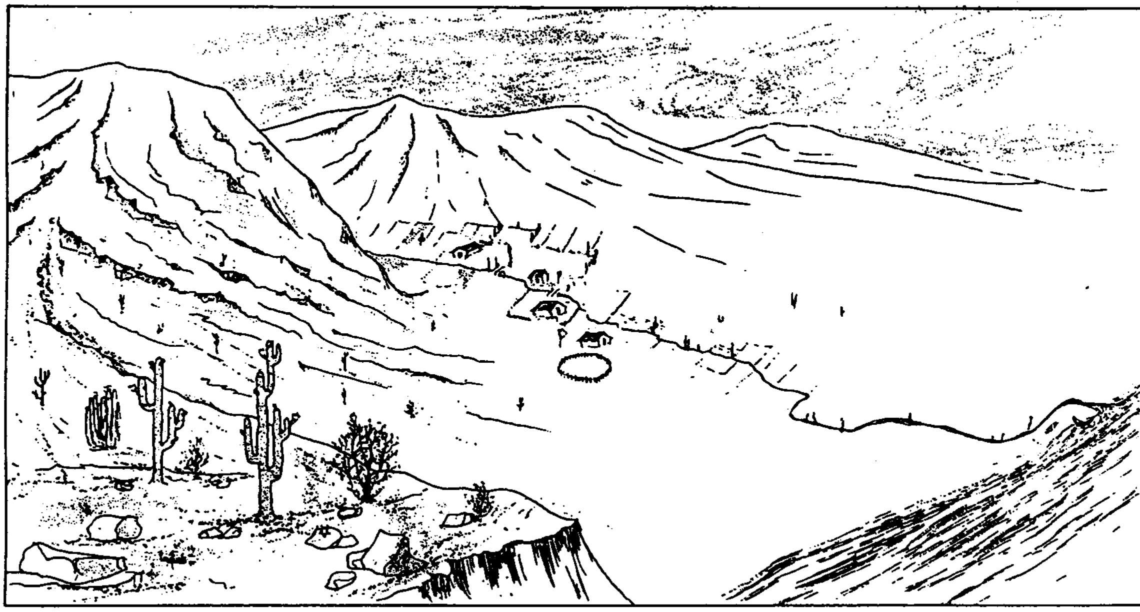

Fig. 3: Present (simplified) landscape of a small river valley village in the Norte Chico showing highly disturbed ecosystems and bioresources suffering from "artificial negative selection".

El paisaje actual (pero simplificado) de una comuna o pueblo tradicional en el Norte Chico, con evidencia de ecosistemas perturbados y recursos naturales muy degradados por la "selección artificial negativa".

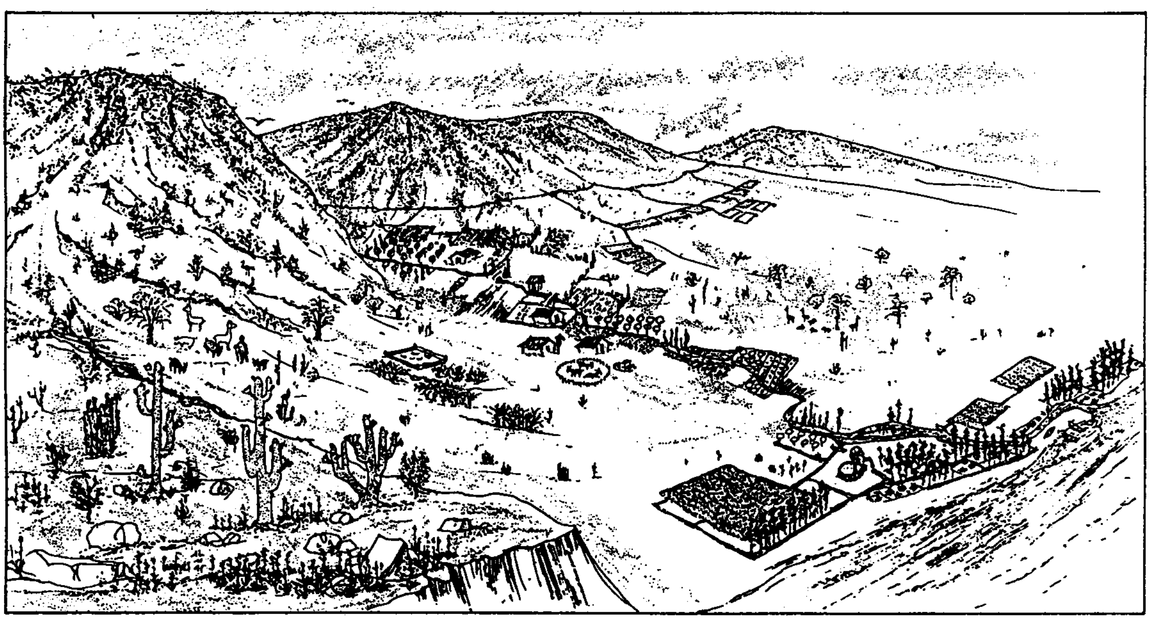

Fig. 4: The full potential for biodiversity and reintegration for the same landscape shown in Fig. 3 once agriculture and livestock husbandry are linked to a landscape and ecosystem approach including a strategy of positive selection.

El potencial del mismo paisaje encontrado en la Fig. 3 cuando los sistemas agropecuarios funcionan en un programa de desarrollo holístico del ecosistema y del paisaje incluyendo una estrategia de "selección positiva".

ded soil fertility allow the development of sustainable agriculture and animal husbandry, even in smaller river bains, such as the one depicted here. These improvements, combined with revised management of natural resources, including wildlife, could vastly improve the attractiveness of the region for inhabitants and, one day perhaps, vacationing visitors.

Floristic and faunal biodiversity as well as agroecological productivity are on the rise in Fig. 4, as desert-adapted native crops and fodder and fuelwood plantations reduce pressure on wild plants and animals. Domesticated livestock herds are mixed (e.g., sheep, goats are now joined by llamas and alpacas); grazing of wild vegetation is closely managed and supplemented by agricultural byproducts and other fodder resources collected and brought to animals, e.g., chañar (*Geoffroea decorticans*) and algarrobo (*Prosopis* spp.) pods; paramela (*Adesmia* spp.) and pintoa (*Pintoa chilensis*) foliage. All of these species except pintoa are biological nitrogen-fixers and can thus improve soils as they provide direct economic services.

Alfalfa grows and produces well in the Norte Chico and, given adequate water management, it could be an important complement to other fodder resources. A three-tiered approach would be quite suitable here, such as has been developed in the espinales further south (see above, and Ovalle *et al.* in review a, 1991), since alfalfa could be readily inserted into existing schemes, while establishment and integration of trees and shrubs will certainly take much longer. (Selected ecotypes of hualputra (*Medicago polymorpha*) could also be tried in the Norte Chico.)

Furthermore, efforts must be undertaken to enhance milk quality in the region, starting with improved sanitary conditions for the animals. New technologies would allow the processing of cheese and other milk products more suitable for transport and conservation in hot, arid lands than fresh milk. Such relatively simple innovations would enable small communes to insert their produce into a modern commercialization and marketing scheme, suppling nearby towns and rural markets. Given supplementary veterinary services, as well as R & D on the landscape-scale integration of irrigated alfalfa and some of the other fodder resources mentioned above, and the institution of positive selection of wild plant resources, improved, enlarged herds could be managed by rural communes to produce significantly increased milk and milk product output in the Norte Chico.

Native spring flowers and bulbs, such as añañuca (*Rhodophiala* spp.), azulillo (*Pasithea* spp.), mariposa del campo (*Alstroemeria* spp.), huilli (*Leucocoryne* spp.), pajarito (*Schizanthus* spp.) and terciopelo (*Argylia radiata*) could be grown in small plots below the village. The spectacular flower stalks of these native plants are currently sold to tourists in spring and summer along roadsides, but could also be transported to city markets by growers, and even possibly flown out of La Serena or Iquique to flower markets around the world. Flower and bulb plots could be irrigated by surface-channeled run-off water to increase yields. In addition, deep wells should be exploited to provide extra water to flower plots in critical periods of growth. Species tolerant of slightly saline ground water could be selected and developed.

Selected cultivars of the chagual (*Puya* spp., Bromeliaceae) could be grown in the Norte Chico with little or no irrigation (Fig. 4, left foreground), as a novel vegetable crop similar to hearts-of-palm. Native columnar cacti, including quisco (*Eulychinia* spp.) and copao (*Trichocereus chilensis* and *T. coquimbanus*) provide delicious fruit (Muñoz Schick 1985, Aronson 1990), and selected, heavy-bearing individuals could be propagated vegetatively and planted in appropriate sites, just as has been done for Mexican *Opuntia* varieties, and is now being attemped for some Mexican columnar cacti as well (Nerd *et al.* 1989).

Higher up on the slopes (in Fig. 4), wild chinchillas are once again abundant, along with native raptors and avifauna. With government subsidies, experimental chinchilla farming should be tested, just as Echegoyán (1923) proposed 70 years ago. The endemic shrub *Balsamocarpon brevifolium* (algarrobilla), whose pods are the chinchilla's favorite food, could be planted nearby with little or no need for irrigation (Aronson 1990). Sufficient large shrubs of this species survive in the Norte Chico and Norte Grande to provide plentiful seed for propagation. Alternatively, chinchilla for production could be restricted to the large areas of natural flora and fauna reserves, while their exploitation would be rigorously restricted to members of local communes. In these reserves, other native fauna to be protected include not only native camelids (vicuña, alpaca and guanaco), but also *Pudu pudu* (pudu) and the large terrestrial rhea, *Pterocnemia pennata garlepi* (ñandu petiso or "ostrich of the cordillera"). This latter species might well be of interest for animal husbandry for meat, eggs, feathers and skin.

Arid land foresters should initiate forest reserves of guayacán (*Porlieria chilensis*), carbonillo (*Cordia decandra*), *Krameria*, *Acacia*, chañar, *Prosopis* well away from the village. These trees could be harvested on a long-term (25-100 years) rational basis, or else managed for wildlife refuges, watershed protection and, ultimately, ecotourism use. In either case, their value to the village and the region could be great, given adequate attention to selection and propagation of elite genetic material, conservation of viable populations, and appropriate silvicultural and post-harvest product development. Such reserves would amount to a landmark example of "positive selection" of native bioresources.

R & D Timetable

It goes without saying that the higly optimistic vision of agroecological diversity depicted here can not be achieved in a short time, nor without considerable investment in research and development (cf. Felger & Babhan 1978, for a comparable scenario based on Sonoran desert bioresources). Some readers may even consider this scenario too far removed from current reality to merit serious attention. Yet, just as in the case of the espinales further south, we argue that a short–, mid– and long-term master plan is needed in the Norte Chico, and that if an optimistic approach is not adapted as a long-term strategy, nothing important will ever really change.

To begin, well-known arido-crop shrubs such as the endemic *Atriplex repanda* (and other related species) could increase fodder productivity in the short-term (Lailhacar *et al.* 1981, Olivares & Gastó 1981). Pitting and other surface treatments as well as more elaborate rainfall-harvesting systems should be tested to increase infiltration and plant productivity in concentrated areas. In our opinion, at least a dozen native bulb species could be immediately put into experimental cultivation as cash crops, while selection and genetic improvement could be initiated concurrently. It may be objected that a cash market and export economy does not at present exist in the region outside of the most favored river vallies. Yet a market infrastructure does already exist nearby for fruits, wine and vegetables. We see no reason why this could not be done for native flowers as well.

Mid-term, nitrogen-fixing, drought– and salt-tolerant casuarinas (e.g., *C. cunninghamiana* and *C. equisetifolia*), could be used as windbreaks around flower plots and simple diversion systems or catchment basins could provide the necessary irrigation to insure an annual harvest, irrespective of fluctuations in annual rainfall. Low-energy technology exists for growing proven drought-tolerant firewood trees (e.g., coppiced *Acacia*, *Eucalyptus*, *Casuarina*, and *Tamarix aphylla*) in rainfall-harvesting catchments (Lovenstein *et al.* 1991, Zohar *et al.* 1988, Aronson *et al.* 1987) could be adapted to replace the destructive, anarchic collection of firewood from dwinling populations in the distant hills (more artificial negative selection). Concurrently, a broad-reaching plan for the conservation and anagement of endangered native plants (see Appendix) and animals should be established during this phase.

For example, the handsome endemic tree guayacán (*Porlieria chilensis*; Zygophyllaceae), of important economic for woodworking of various small items sold to tourists (Aronson 1990), is badly overexploited throughout its range and in clear danger of extinction (CONAF 1985). Productivity and quality of guayacán wood could be much improved if the trees were protected, managed properly and allowed to reach decent size before harvesting. Ideally, replanting with selected germplasm would be combined with watershed protection and soil conservation schemes on steep slopes.

Similarly, algarrobos (especially *Prosopis alba* var. *alba*) and "elite" individuals of chañar (*Geoffroea decorticans*) could be put to much more use as food, fodder and agroforestry trees than they are at present, particularly where phreatic water tables are high (Felker 1979, National Academy of Sciences 1980, Ovalle *et al.* 1990). These and other nitrogen-fixers could –in the space of 10 to 20 years– have very significant impact on the mineral and organic matter contents and microflora of degraded soils. Reintroducing and protecting native trees and shrubs should also have beneficial impact on associated herbaceous vegetation serving as pasture for domestic livestock.

In the realm of agro-industry, several native plants of northern Chile have unusual chemicals of potential use pharmaceutically or industrially. For example, two native shrubs of northern Chile, *Grindelia tarapaca* and *G. glutinosa* (Asteraceae), yield labdane diterpenoids, useable as tackifiers, glu, varnish, insecticides, etc. (B.N. Timmermann & E. Fuentes personal communication). The related *G. camporum* of North America has already being planted in pilot scale test plots in Australia.

Long-term, new (and modified ancient) methods of harvesting surface runoff (Fig. 4, right hand hillside) as well as seawater agriculture and forestry (Fig. 4, righ-hand foreground) should be tested in northern Chile and, if successful, used to supplement meagre, erratic supplies of rainfall and dwindling supplies of non-salty groundwater.

RESEARCH GAPS AND REAL WORLD OBSTACLES

Technical gaps

Interventions are urgently needed to restore lost nitrogen and organic matter supplies as well as microorganisms and detritivore populations in the soil. Yet, it will be objected, aridity and unpredictability of rainfall are major growth limitations for soil biota. Indeed, for northern Chile and other ASAL, it is necessary to find appropriate and effective rhizobial and mycorrhizal inoculants for use with plant introductions in degraded, arid soils. But we argue that technical problems are less serious here than psychological, socioeconomic and cultural ones.

Agronomic and post-harvest handling problems will of course need to be addressed for each new crop or other proposed innovation in northern Chile. But, in our opinion, the potential export value of the novel desert fruits, vegetables and cut flowers mentioned above is very high, provided that sufficient quantities could be produced and that an adequate infrastructure were developed to assure a steady flow to regional markets. Thus, funding for R & D on these new crops should be obtainable.

Just as crops would be more diversified in our optimistic scenario, so would livestock production diversify in the Chilean ASAL. Camelids, or course, would supplement cattle, sheep and goats, but also perhaps degú (*Octodon degu*) nutria (*Myocastor*) and wild ostrich (*Pterocnemia pennata garlepi*). Remaining populations of the endangered, and non-domesticable fauna of the southern Andes should be just as rigorously protected as the rare and endangered plant species. Once populations build back up to appropriate sizes, some of these native animals could then be harvested on a rational basis. More ambitiously, R & D could be undertaken to examine the viability of raising some of these animals domestically in the region. As in export-based agriculture and agro-industry, quality rather than quantity should be emphasized.

Finally, it will be necessary to develop rational systems of water management in the region. Until water supply for people, crops and animals is better controlled and apportioned, virtually no aspect of our scenario is feasible. Whether communal organization will continue or be entirely replaced by private enterprises is a related issue to be addressed, and will obviously have great impact on any new water conservation and utilization schemes.

Financial gaps and obstacles

One other critical need is to identify sources of funding for the needed research and development. Given their precarious subsistance-level economies, and the highly unpredictable environment in which they live, local people can not and will not invest in unknown methods, crops or domesticates. Someone else will have to pay for the R & D.

Socio-cultural obstacles

Indeep the major obstacles to realization of our scenario, or any other alternative future for the Norte Chico, may be social and cultural rather than technological or financial. A highly precarious subsistance economy currently prevails; how to make the transition towards a market economy at least partially based on cash crops is the main problem to be addressed. Poverty-stricken people have understandably great difficulty in conceiving the cultivation of products (fur, feathers, bulbs and cut flowers) that are not of immediate practicality to themselves. However, we argue that only through greater insertion into regional, national and one day, international, markets can the quality of life in these communes be sufficiently raised as to initiate healthy economic development and allow ecosystem rehabilitation at the same time. Yet it is essential that the farmers and pastoralists themselves not become the victims of commercial middlemen nor the pawns of the vagaries of foreign commodity speculators. It is true that past efforts to develop tomato and cumin crops in the region have not led to dramatic influxes of cash (M. Etienne, pers. comm.). However, we suspect this is because they were not part of a community-based R & D plan, but rather were developed with private capital from outside the region. If successful, the influx of cash deriving from cash crops would raise confidence and willingness to seek insertion into a regional marketing network.

At the same time, new modes of production obviously must be compatible with existing cultural and sociological patterns (Etienne *et al.* 1983, D'Herbes 1988, Azócar & Lailhacar 1990). Thus, in northern Chile firewood and fuel must be provided locally even while efforts could be made to convince decision–makers in Santiago to subsidize kerosene and kerosene stoves for villagers in the arid regions so as to reduce pressure on standing biomass.

Similarly, goats must be tolerated in the short run, because local people simply will not replace them with other livestock until they are completely convinced it is a good idea economically. Indeed, well-managed goat herds are not necessarily part of the problem. It is only when the husbandry of goats (and other livestock) is completely anarchic that their presence represents and impediment to integrated landscape and ecosystem planning, conservation and development.

DISCUSSION

In the Norte Chico, as in central Chilean espinales, local habits and practises will have

APPENDIX

Partial list of vulnerable and rare plant species of the arid and semiarid regions of Chile (CONAF, 1985) with clear economic potential. A large number of ornamental flowering geophytes are not included

Lista parcial de especies de plantas raras y vulnerables de las regiones áridas y semiáridas de Chile (CONAF, 1985) con claro potencial económico. No se incluye un gran número de geofitas con flores ornamentales

Species (common name)	Regions	Uses
VULNERABLE TO EXTINCTION		
Beilschmedia berteroana (Gay) Kos.		fodder
B. miersii (Gay) Kos. (Belloto del Norte)	V, VI, M.R.[1]	fodder
Carica chilensis (Planch ex DC) Solms.-Laub. (Palo gordo)	IV, V	fruit
Cordia decandra h. et A. (Carbonillo)	III, IV	fuelwood
Krameria cistoidea H. et A. (Pacul)	III, IV	fodder
Porlieria chilensis Johnst. (Guayacán)	IV-VI, M.R.	fine wood
Puya coquimbensis Mez. (Chagual de Coquimbo)	IV	vegetable
P. venusta Phil. (Chagualillo)	IV, V	vegetable
RARE		
Adesmia balsamica Bert. & Colla (Paramela de Puangue)	V	fodder
A. resinosa Phil. (Paramela de Til-Til)	V, M.R.	fodder
Pintoa chilensis Gay (Pintoa)	III, IV	fodder
Jubaea chilensis (Mol.) Baillon (Palma chilena)	IV, V, M.R.	liqueur, oil, thatch

[1] Metropolitan Region, around Santiago.

to change before new scenarios can be enacted. New management techniques and new strategies must be developed. Human populations and grazing pressures must be maintained at appropriate levels and a balance between communal and privately-owned lands must be sought as well.

Some valuable and readily transferable R & D has been carried out in various drylan regions, yet much more is needed to reverse current trends of desertization and ecosystem degradation. Both in the espinales of central Chile, and the Norte Chico, a landscape and ecosystem approach is needed. Since poverty-bound rural people and fragile biotic and abiotic resources must be taken into account, productive agroecological steady states must be sought. However, from a purely ecological point of view, it seems clear that maximum protection of resources and ecosystem stability need to be fostered as well. We are of course aware of the very important obstacles standing in the way of realization of the optimistic rehabilitation scenario presented here, but we believe it is one of the roles of researchers to propose alternative futures, even if the current situation leads politicians, economists and other "experts" to doubt the feasability of their realization. If "positive selection" and creative bioresource management were ever to replace artificial negative selection, dramatic transformations of both ecosystems and landscapes in arid and semiarid lands could result.

ACKNOWLEDGMENTS

The authors wish to thank Juan Armesto, Mary Kalin-Arroyo, Julio Gutiérrez, Gary Cunningham, Wesley Jarrell, Walt Whitford, and all the participants at the October 1991 La Serena Workshop, as well as Melica Muñoz Schick and Roberto Rodríguez for stimulating discussions. We also thank Michel Etienne, Edouard Le Floc'h, Henry Noel Le Houérou for the constructive comment on the manuscript. René Ferris kindly drew the figures.

LITERATURE CITED

ALLEN MF (1989) Mycorrhizae and rehabilitación of disturbed arid soils: processes and practises. Arid Soil Research & Rehabilitation 3: 229-241.

ARMESTO JJ & STA PICKET (1985) A mechanistic approach to the study of succession in the Chilean matorral. Revista Chilena de Historia Natural 58: 9-17.

ARONSON J (1990) Desert plants of use and charm from northern Chile. Desert Plants 10: 65-74, 79-86.

ARONSON J, C OVALLE & J AVENDAÑO (1991) Early growth rate and nitrogen fixation potential in 44 legume species grown in two soil types in central Chile. Forest Ecology & Management 47: 225-244.

ARONSON J, C FLORET, E LE FLOC'H, C OVALLE & R PONTANIER (1993) Restoration and rehabilitation of degraded ecosystems: I. A view from the South. Restoration Ecology 1: 8-17.

ARONSON J, C FLORET, E LE FLOC'H, C OVALLE & R PONTANIER (in review a) Restoration and rehabilitation of degraded ecosystems. II. Case studies in central Chile, southern Tunisia and northern Cameroon. Restoration Ecology.

ARONSON J, C OVALLE & J AVENDAÑO (in review b) Espinal rehabilitation in central Chile. II. New models and paradigms. Agriculture, Ecosystems & Environment.

AVENDAÑO J, C OVALLE & A DEL POZO (1990) Pastoreo de Hualputras con ovinos. Informe Técnico 1989-1990. Area de Producción Animal. Estación Experimental Quilamapu, Chillán, Chile: 302-307.

AZOCAR P & S LAIHALCAR (eds) (1990) Bases ecológicas para el desarrollo agropecuario de la zona de clima mediterráneo árido de Chile. Terra arida (Chile) 8: 221-301.

BAHRE CJ (1979) Destruction of the Natural Vegetation of North-Central Chile. University of California Press, Berkeley.

BONILLA S (ed) (1977) Estudio de caso sobre la desertificación: Región de Combarbalá, Chile. Proceedings UNESCO Conference on Desertification, Nairobi, Kenya. INIA. Santiago.

BALDUZZI A, R TOMASELLI, I SEREY & R VILLASEÑOR (1981) Degradation of the mediterranean type of vegetation in central Chile. Ecología Mediterránea 7: 223-240.

CHATTERTON B & L CHATTERTON (1984) Alleviating land degradation and increasing cereal and livestock production in North Africa and the Middle East using annual medicago pastures. Agriculture, Ecosystems & Environment 11: 117-129.

CONAF (1985) Actas Simposio Flora Nativa Arbórea y Arbustiva de Chile Amenazada de Extinción. Corporación Nacional Forestal, Ministerio de Agricultura, Santiago.

COSIO F & R DEMANET (1984) Estudio: análisis de sistemas caprinos de la zona mediterránea semiárida de Chile. Quillota y Llay-Llay, V Región. Publicación de la Estación Experimental La Palma, Quillota.

CRESPO D (1985) Intensification of sheep production under grazing of marginal lands of the Mediterranean region. FAO Symposium, Genova, Italy.

DEL POZO A, C OVALLE & J AVENDAÑO (1989a) Los medicagos anuales en Chile. I. Comparación con Australia. Agricultura Técnica (Chile) 49: 260-267.

DEL POZO A, C OVALLE & J AVENDAÑO (1989b) Los medicagos anuales en Chile. II. Ecofisiología. Agricultura Técnica (Chile) 49: 268-274.

DEL POZO A, C OVALLE, J AVENDAÑO & P DEL CANTO (1989c) Los medicagos anuales en Chile. III. Perspectivas de la rotación medicago-trigo en el secano interior de la zona mediterránea. Agricultura Técnica (Chile) 49: 275-280.

D'HERBES JM (1988) Analyse agro-écologique des systèmes de production pour le developpement rural integré des zones arides. Chile IVème Región, II, III, IVème Parties.

Rapport de fin de contrat. CNRS/CEPE, Montpellier, France.

ETIENNE M, C CAVIEDES, C GONZALEZ & C PRADO (1982) Cartografía de la Vegetación de la Zona Arida de Chile. Terra Arida 1: 1-78.

ETIENNE M, C CAVIEDES & C PRADO (1983) Bases ecológicas para el desarrollo de la zona árida mediterránea de Chile. Elementos para una planificación a nivel regional, zona-test de Tunquen. Montpellier, Santiago.

ETIENNE M, LA FAUNDEZ & J VALDES (1987) La desertificación en la zona árida de Chile. Terra Arida (Chile) 6: 1-44.

FUENTES ER & ER HAJEK (1978) Interacciones hombre-clima en la desertificación del Norte Chico. Ciencia e Investigación Agraria 5: 137-142.

FUENTES ER & ER HAJEK (1979) Patterns of landscape modification in relation to agricultural practises in central Chile. Environmental Conservation 6: 265-271.

FUENTES ER & S PRENAFETA (1988) Ecología del paisaje en Chile central. Ediciones Universidad Católica de Chile, Santiago.

GASTO J (1979) Ecología: El hombre y la transformación de la naturaleza. Editorial Universitaria, Santiago.

GASTO J, D CONTRERAS, F COSIO & R DEMANET (1990) Degradación y rehabilitación de la zona de clima mediterráneo árido de Chile. Terra Arida (Chile) 8: 171-220.

HABIT MA (1981) *Prosopis tamarugo:* fodder tree for arid zones. FAO Plant Production and Protection Paper 25. Rome.

HERRERA A, C OVALLE & L LONGERI (in review) Estudio de efectividad de algunas cepas de *Rhizobium meliloti* con hualputra (*Medicago polymorpha*) colectadas en Chile. Agricultura Técnica (Chile).

LAIHALCAR S, R MORENO, J CEPEDA, A CRISTI, P AZOCAR & I BADILLA (1981) Identificación y selección de ecotipos de sereno (*Atriplex repanda* Phil). PRIZAS, Universidad de Chile, Santiago.

LLOYD JW (1976) The hydrogeology and water supply problems in north-central Chile. Pacific Science 30: 91-100.

MASSE D (1992) Amélioration du régime hydrique de sols dégradés en vue le leur réhabilitation: cas des vertisols du Nord-Cameroun. Ph.D. Thesis. Toulouse: Institut National Polytechnique.

MUÑOZ SCHICK M (1975) Gerónimo de Bibar, notable observador naturalista en la alborada de La Conquista. Boletín Museo de Historia Natural Chile 34: 5-27.

MUÑOZ SCHICK M (1985) Flores del Norte Chico. Dirección de Bibliotecas, Archivos y Museos, La Serena, Chile.

ODUM EP (1969) The strategy of ecosystem development. Science 164, 262-270.

OLIVARES A & J GASTO (1981) Organización y manejo de ecosistemas con arbustos forrajeros. Facultad de Agronomía, Universidad de Chile, Santiago, 146 pp.

OVALLE C (1986) Etude du Système Ecologique Sylvo-Pastoral à *Acacia caven* (Mol.) Hook. et Arn: Applications à la gestión des ressources renouvables dans l'aire climatique méditer ranéenne du Chili. Ph.D. Thesis. Université des Sciences et Téchniques du Languedoc, Montpellier, France.

OVALLE C & J AVENDAÑO (1987) Interactions de la strate ligneuse avec la strate herbacée dans les formations d'*Acacia caven* (Mol.) Hook. et Arn. au Chili. Oecologia Plantarum 8: 385-404.

OVALLE C, J AVENDAÑO & A DEL POZO (1988) Caracterización de las formaciones de espinal del área del secano interior subhúmedo y húmedo. Pp. 134-145 Informe Técnico 1987-1988. Area de Producción Animal. Estación Experimental Quilamapu, Chillán, Chile.

OVALLE C, J ARONSON, A DEL POZO & J AVENDAÑO (1990) The espinal: agroforestry systems of the mediterranean-type climate region of Chile. Agroforestry Systems 10: 213-239.

OVALLE C, J ARONSON, J AVENDAÑO, R MENESES, R MORENO & L VILLAFLOR (1991) Dryland fodder legume trees, shrubs and associated rhizobacteria for central Chile. Establishment and preliminary field evaluation: 401-404. Proceedings IV[th] International Rangelands Congress, CIRAD, Montpellier, France.

OVALLE C, J ARONSON, J AVENDAÑO & H ALVAREZ (in press b) Tagasaste (*Chamaecytisus proliferus* spp. *palmensis*), un árbol forrajero leguminoso con potencial para sistemas agrosilvipastorales en Chile mediterráneo. Agricultura Técnica (Chile).

OVALLE C, J ARONSON, J AVENDAÑO (in review a) Espinal rehabilitation in central Chile. I. Introduction and evaluation of nitrogen-fixing legumes, multipurpose trees and an annual medic. Agriculture, Ecosystems & Environment.

OVALLE C, J AVENDAÑO & J ARONSON (in review b) Cartographic study of land use and *Acacia caven* "espinales" in the subhumid portion of central Chile. Journal of Vegetation Science.

PUCKRIDGE DW & RJ FRENCH (1983) The annual legume pasture in cereal-ley farming systems of southern Australia: a review. Agriculture, Ecosystems & Environment 9: 229-267.

RAUH W (1985) The Peruvian-Chilean Deserts. In: Evenari M, Noy-Meir I & DW Goodall (eds), Hot deserts and arid shrublands. Vol. A: 239-266. Elsevier, Amsterdam.

RODRIGUEZ R, O MATTEI & M QUEZADA (1984) Flora arbórea de Chile. Editorial de la Universidad de Concepción, Concepción.

RUNDEL PW, MO DILLON, B PALMA, HA MOONEY, SL GULMON & JR EHLERINGER (1991) The phytogeography and ecology of the coastal Atacama and Peruvian deserts. Aliso 13: 1-49.

SERRANO F & HN JARA (1975) Prospección de la situación ovina y bovina en el secano interior, provincia del Maule, comuna de Cauquenes, Chillán, Chile. INIA-IICA.

SNOOK LC (1982) Tagasaste (Tree Lucerne). *Chamaecytisus palmensis*. A shrub with high potential as a productive fodder crop. Journal of the Australian Institute of Agricultural Sciences.

SOLBRIG O (1984) Agriculture and Livestock. Mountain Research and Development 4(2): 151-162.

SPRUGEL DG (1991) Disturbance, equilibrium, and environmental variability: what is "natural" vegetation in a changing environment? Biological Conservation 58: 1-18.

VITOUSEK P & REINERS WA (1975) Ecosystem succession and nutrient retention: a hypothesis. BioScience 25: 376-381.

WHITFORD WG (1986) Pattern in desert ecosystems: water availability and nutrient interactions. In: Dubinsky Z, & Y Steinberger (eds) Environmental Quality and Ecosystem Stability, Vol. III: 109-117. Bar Ilan University Press, Ramat Gan, Israel.

WHITFORD WG (1988) Decomposition and nutrient recycling in disturbed arid ecosystem. In: Allen EB (ed) The reconstruction of disturbed arid lands: 136-161. Westview Press, Boulder, Co. USA.