African Journal of Agricultural Research Vol. 5(25), pp. 3542-3552, December 2010 Special Review
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR10.005
ISSN 1991-637X ©2010 Academic Journals

Review

Application of design theory for restoring the "black beach" degraded rangeland at the headwater areas of the Qinghai-Tibetan Plateau

S. K. Dong[1]*, J. P. Li[1], X.Y. Li[1], L. Wen[1], L. Zhu[1], Y. Y. Li[1], Y. S. Ma[2] , J. J. Shi[2], Q. M. Dong[2], and Y. L. Wang[2]

[1]School of Environment Beijing Normal University, Beijing, 100875, China.
[2]Qinghai Academy of Animal Science and Veterinary Medicine, Xining, 810003, China.

Accepted 20 December, 2010

Severe degradation of alpine rangeland into the "black beach" at the headwater areas of the Qinghai-Tibetan Plateau driven by human disturbance and climatic change is limiting the sustainable development of ecological, social and economic systems in both local and downstream regions. Appropriate restoration theory is needed to guide the technical and managerial strategies to restore the degraded alpine rangeland and maintain the upstream-downstream relationships in the ecological web. A ten-year research program of restoring the "black-beach" degraded rangelands at the headwater areas of the Qinghai-Tibetan Plateau was summarized in this study to clarify the restoration theory guiding the interventions for rehabilitating these rangelands and provide some examples of successful rehabilitations for worldwide alpine rangeland ecosystems. It was found that the design theory was more applicable than the self-design theory in guiding the restoration interventions for "black-beach" degraded rangeland. Replanting guided by the design theory was effective in reconstructing the alpine rangeland vegetation and improving the ecological and economic values of the alpine rangeland ecosystem at the headwater areas of the Qinghai-Tibetan Plateau. Seed rain, seed bank and seedling germination should be included in post-restoration monitoring and assessment of restoration practices.

Key words: Replanting, vegetation composition, ecological values, economic benefits.

INTRODUCTION

Located in the center of Qinghai-Tibetan Plateau, the "roof" of the world, the headwater areas of three major rivers in Asia; Yangtze River, Yellow River and Lancang-Mekong River, covers 18.9 million km^2 in land size, amounting to a quarter of the territory of Qinghai Province, the fourth largest province in China. Over 85% of the land in these areas are covered by alpine range-land (including alpine meadow, alpine shrub- meadow and alpine steppe) and grazed by indigenous livestock such as yak and the Tibetan sheep (Wang and Cheng, 2001). These areas have served as the dominant grazing pastures for Tibetan communities in history and are regarded as one of the major pastoral production bases in China (Ma et al., 1999). However, rangeland degra-dation driven by human disturbance and climatic change is limiting the sustainable development of ecological, social and economic systems at local and regional levels (Ma et al., 1999; Wang and Cheng, 2001; Shang and Long, 2005). It is reported that nearly half of the alpine rangeland in these areas have been degraded in the past 40 years, with an increased degradation rate of 3.9% of total areas in the early 1970s to 7.6% of total areas in the

*Corresponding author. E-mail: dongshikui@sina.com, DSK@irs.bnu.edu.cn. Tel: ++ 86 1058802029. Fax: ++ 86 10 58800397.

Figure 1. View of "Black-beach" degraded Alpine rangeland in summer.

Figure 2. View of "Black-beach" degraded alpine rangeland in winter.

late 1990s (Wang and Cheng, 2001). Currently, around 26% of the alpine rangeland is severely degraded as the "black beach" or the "black-soil-land" (Figures 1 and 2), the bare land in winter and the sparsely-covered land with annual weeds or poisonous plants in summer (Li and Huang, 1995; Ma et al., 1999; Ma et al., 2002; Shang and

Long, 2005). Degradation of alpine rangeland by overgrazing associated with over-exploitation (mining, tourism, etc) and harvesting (medicinal plants collection, illegal hunting, etc) will increase potential evapo-transpiration levels thereby promoting climate warming and the degradation process (Du et al., 2004; Wang et al., 2006).

Degradation has decreased the ecological functions of alpine rangeland in the headwater areas of Qinghai-Tibetan Plateau as the water reservoir, carbon pool, biodiversity bank, climate regulator, pastoral production base as well as Tibetan socio-culture carrier in different perspectives not only resulting in eco-environmental disasters of biodiversity loss productivity decrease, soil erosion and land desertification, etc. for the local region, but also in environmental problems of water scarcity, sediment split-up, dust storm, etc. for down-stream regions along the Yangtze, Yellow and Lancang-Mekong rivers (Li and Huang, 1995; Ma et al., 1999; Wang and Cheng, 2001; Ma et al., 2002; Shang and Long, 2005). It was reported that 15 to 23% of indigenous species are endangered due to the degradation of the alpine rangeland, especially the degradation of the wet meadow, the key habitat for many alpine organisms at the headwater areas of the Qinghai-Tibetan Plateau (Dong et al., 2002). The water resources of the Yellow river exported from Qinghai province to the downstream areas decreased by 23% since the1970s due to the decrease of lakes and drying-up of some branches at the headwater areas and sedimentation in the downstream which increased to 4600 × 104 t annually due to the decreased capacity of rangeland degradation on soil erosion (Lan, 2004). These critical situations have challenged Chinese scientists and authorities to develop technical and managerial strategies to restore the degraded rangeland, so as to protect the eco-social environments of head-water areas of the Qinghai-Tibetan Plateau and maintain the upstream-downstream relationships along the Yangtze, Yellow and Lancang-Mekong rivers.

To restore, based on the meaning of the word itself, is to bring back to an original condition, which implies that something has been altered. The action of restoration is to return to its previous stage, recover its former state, regain its processes, and repair its damage. On these bases, rangeland restoration can be defined as a return of the rangeland ecosystem to a close approximation of its natural condition, recover its ecological function so as to regain its abiotic environment and biotic communities, and repair its connection to nature. However, questions arise, regarding what conditions do we want to restore and how far back in time should we go as a paradigm for restoration? How often and what level we can guide the restoration process? Whether we have sufficient knowledge in designing a rangeland restoration? Understanding of ecosystem dynamics, the place of humans in historic ecosystems, and changed environmental settings owing to rapid environmental change all impact on decisions concerning which restoration interventions are appropriate. In principle, restoration ecology can provide the conceptual and practical frameworks to guide management interventions aimed at repairing environmental damage, and ecological restoration should go beyond a “simple landscape exercise” emphasizing the application of ecological models and theories to restoration practice (Bradshaw and Handley, 1982; Bradshaw, 1987).

The restoration interventions vary from a "do nothing" approach to a variety of physical and biological interventions aimed at speeding up or altering the course of ecosystem recovery (Bradshaw, 1992). These restoration interventions are generally associated with two major principles of restoration ecology, self-design and design theories. Self-design theory is to establish physical and chemical conditions that will favor desired species, anticipate changes, and assume that species (planted or volunteer) will ‘find’ suitable habitats (Zedler, 2000). Design theory is to reconstruct an ecosystem that has been seriously damaged, or to replant a biological community that has been severely destructed, or to recreate a habitat that has been badly destroyed with no fixed points (Middleton, 1999). Which theory is more applicable in guiding the restoration interventions of fragile but severely-degraded alpine rangeland ecosystem at the headwater areas of the Qinghai-Tibetan Plateau is an unanswered question to be addressed. In this work, the researches and practices implemented on restoring the “black-beach” degraded rangelands at the headwater areas of the Qinghai-Tibetan Plateau in the past 10 years to clarify the restoration theory guiding the interventions for rehabilitating these rangelands was summarized and some case studies that are examples of successful rehabilitations for worldwide alpine rangeland ecosystems were provided.

PLANT COMMUNITIES OF DEGRADED RANGELAND

To devise ecological restoration strategies and actions, it is necessary to first identify the results of degradation succession. It has been found that the plant community of the alpine rangeland at the headwater areas of the Qinghai-Tibetan Plateau changed from primary vegetation dominated by sedges or sedge-grasses to secondary vegetation dominated by forbs in the process of rangeland degradation. The degradation succession of rangeland vegetation was different with geographic location and driving forces, as reflected by the different plant communities as follows (Table 1):

Aconitum pendulum association (Type I)

This is the pioneer vegetation of degraded sedge or sedge-grass meadow under short-period stress of overgrazing or rodent disturbance and occurs on the

Table 1. Features of plant communities of degraded alpine rangelands at the headwater areas. (Source: Ma et al., 2006)

Feature	Plant community type						
	I	II	III	IV	V	VI	VII
Habitat elevation (m)	3700	3800	4000	4000	4100	4100	4100
Species number	28	29	36	22	12	17	8
Plant cover (%)	55.3	57.6	71.0	74.8	55.5	55.3	78.0
Aboveground biomass (g/m^2)	1221.2	693.2	754.4	530.6	799.6	555.8	636.0
Shannon-Weaver diversity index	1.73	2.16	1.85	1.92	1.41	1.45	1.19
Pielou evenness index	0.52	0.64	0.52	0.62	0.57	0.51	0.57
Proportion of palatable forages in plant cover (%)	7.5	6.0	1.3	5.2	3.0	6.3	8.0
Proportion of palatable forages in aboveground biomass (%)	1.35	0.91	0.24	4.02	0.28	0.36	0.79

riverside terrace and hillside flatland at an elevation of around 3700 m. The plant community is dominated by weedy forbs of *Aconitum pendulum*, and accompanied by non-forage forbs such as *Artemisia dulhreuil*, *Ajuga lupulina*, *Ajania tenuifolia* and *Hierochloe odorata*, etc with low plant cover and palatable forage proportion but high aboveground biomass and plant diversity.

Artemisia sievrsiana - *Ajuga lupulina* association (Type II)

This is the secondary vegetation of degraded sedge meadow under short-period stress of overgrazing or drought occurring on the riverside terrace, flood plain and rocky areas at an elevation of around 3800 m. The plant community is dominated by non-forage forbs of *Artemisia sievrsiana* - *Ajuga lupulina*, and accompanied by unpalatable forbs such as *Microul pseudotrichocarp*, *Elshollzia cillate* and *Thalictrum alpinum,* etc with low plant cover, aboveground biomass and palatable forage proportion with high plant diversity.

Ligularia virgaurea - *Aconitum szechenyianum* association (Type III)

This is the pioneer vegetation derived from sedge meadow under the longtime stress of overgrazing or drought associated with rodent disturbance occurring on the riverside terrace, flood plain and hillside flatlands at an elevation of around 4000 m. This plant community is dominated by unpalatable forbs of *Ligularia virgaurea* and *Aconitum szechenyianum*, accompanied by weeds of *Ajuga lupulina*, *Ajania tenuifolia*, *Euphorbia kozlowii* and *Morina chinensis* etc, with high plant cover and plant diversity with low aboveground biomass and palatable forage proportion.

Polygonum sibiricum - *Potentilla anserine* association (Type IV)

This is the secondary vegetation of degraded sedge or sedge-grass meadow under short-period overgrazing and rodent disturbance occurring on the gentle slope at an elevation of around 4000 m. The plant community was dominated by non-forage forbs of *Polygonum sibiricum* and *Potentilla anserine*, and accompanied by good grass forages of *Poa pratensis*, *Elymus nutans* and some unpalatable forbs such as *Cardamine tangutorum*, *Artemisia sievrsiana*, *Microul pseudotrichocarp* and *Chenopodium glaucum*, etc with high plant cover and plant diversity with low aboveground biomass and palatable forage proportion.

Microul pseudotrichocarp association (Type V)

This is the secondary vegetation of degraded sedge or sedge-grass meadow under short-period stress of overgrazing or drought occurring on the riverside terrace and flood plain at an elevation of around 4100 m. The plant community is dominated by weedy forbs of *Microul pseudotrichocarp*, and accompanied by non-forage forbs such as *Polygonum sibiricum*, *Polygonum pilosum*, *Draba eriopod*, etc as well as some forage grasses such as *Poa pratensis* with low plant cover, aboveground biomass, plant diversity and palatable forage proportion.

Table 2. Change of vegetation biomass and composition of alpine rangelands at different degradation stage with fencing time. (Source: Ma et al., 2006)

Degradation extent	Fencing time (year)	Aboveground biomass (g/m^2)	Composition of different functional groups in aboveground biomass (%)		
			Grass	Sedge	Forb
Non-degraded	1	330.5	54.6	31.8	13.5
	2	348.6	60.2	28.3	11.5
	3	346.0	63	25.6	11.5
Lightly degraded	1	206.5	40.5	32.6	26.9
	2	233.6	45	32	22.9
	3	335.8	59.1	25.5	15.4
Moderately degraded	1	156.6	12.9	9.7	77.4
	2	187.2	34.4	19.4	46.1
	3	198.5	42.9	25.5	31.6
Severely degraded	1	80.6	6.2	3.7	90.1
	2	112.4	8.7	3.1	88.2
	3	135.2	12.2	6.3	81.5
Extremely degraded	1	67.6	1.5	1.5	97
	2	75.8	2.6	1.3	96.1
	3	96.5	5.1	3.1	91.7

Morina chinensis association (Type VI)

This is the pioneer vegetation of degraded sedge or sedge-grass meadow under short-period stress of overgrazing or rodent disturbance occurring on hillside flatland at an elevation of around 4100 m. The plant community is dominated by weedy forbs of *Morina chinensis*, and accompanied by non-forage forbs such as *Ajuga lupulina*, *Artemisia dulhreuil*, *Ajania tenuifolia* and *Lagotis brevituba*, etc with low plant cover, aboveground biomass and palatable forage proportion while moderate plant diversity.

Pedicularis kansuens association (Type VII)

This is the pioneer vegetation of degraded cultivated perennial grassland under short-period stress of overgrazing or rodent disturbance occurring on the riverside terrace and hillside flatland at an elevation of around 4100 m. The plant community is dominated by weedy forbs of *Pedicularis kansuens*, and accompanied by non-forage forbs such as Swertia bifolia, *Aconitum gymnandru*, *Microula pseudotrichocarp* and *Lamiphlomis rotate*, etc with a high plant cover but low aboveground biomass, plant diversity and palatable forage proportion.

FENCING VS. REPLANTING DEGRADED RANGELAND

To select the applicable interventions for restoring “the black-beach” type rangeland, a long-term field investigation to compare the activity of fencing derived from self-design theory and the activity of replanting based on the design theory was conducted. The results of these field investigations as presented in Table 2 indicate

Figure 3. The effect of fencing “Black-beach” degraded alpine rangeland.

that fencing can increase the aboveground biomass of all rangelands at different degradation stage. As for lightly and moderately-degraded rangelands, fencing effectively decreased the proportion of weedy forbs, while significantly increasing the proportion of good forage grasses and sedges in the aboveground biomass of the communities. In terms of severely- and extremely-degraded rangelands, this intervention was ineffective in increasing the proportion of forage grasses and sedges and decreasing the proportion of weedy forbs in the aboveground biomass of the communities (Figure 3). With increase in fencing time (years), the gaps of aboveground biomass and forage proportion between lightly and non-degraded rangelands, and moderately and lightly degraded rangelands decreased dramatically. However, a big difference in aboveground biomass and vegetation composition were observed when severely and extremely-degraded rangelands were compared with moderately, lightly-and non-degraded rangelands. This phenomenon implies that the intervention of fencing derived from self-design theory was not applicable for restoring severely and extremely-degraded rangelands at the headwater areas of Qinghai-Tibetan Plateau.

The field investigations on the restoration of replanting show that both aboveground biomass and vegetation composition can be significantly improved by the interventions of reseeding and establishing cultivated grassland (Table 3 and Figure 4.). When the severely and extremely-degraded rangelands were reseeded with native grasses, the aboveground biomass increased 3 times as high as the non-degraded rangeland, and the plant cover, plant biodiversity, proportions of palatable forages in both plant cover and aboveground biomass were promoted as high as the non-degraded rangeland. After the severely and extremely-degraded rangelands were converted into cultivated perennial grasslands of grass mixtures, the aboveground biomass was enhanced 5 times as high as the non-degraded rangeland, and the plant cover, proportions of palatable forages in both plant cover and aboveground biomass were promoted close to those of non-degraded rangeland. This evidence reveals that interventions of reseeding and establishing cultivated grassland derived from design-theory were good options to restore severely and extremely-degraded rangelands at the headwater areas of Qinghai-Tibetan Plateau.

COST-BENEFIT OF REPLANTING INTERVENTIONS

Both economic return and ecological values stemming

Table 3. Comparison of vegetation biomass and composition among non-degraded, severely degraded, extremely degraded and reseeded rangelands with cultivated grassland.

Survey item	Non-degraded rangeland	Severely degraded rangeland	Extremely degraded rangeland	Reseeded rangeland*	Cultivated grassland*
Area (hm^2)	10	10	10	10	10
Aboveground biomass (kg/ hm^2)	1250	520	430	4728	6340
Proportion of palatable forages in aboveground biomass (%)	80	50	10	80	95
Plant cover (%)	100	65	30	90	98
Proportion of palatable forages in plant cover (%)	85	30	10	75	95
Shannon-Weaver diversity index	2.24	3.93	2.89	2.25	1.79

*Restoration strategies applied on severely-degraded and extremely-degraded rangelands.

Figure 4. The effect of reseeding “Black-beach” degraded alpine rangeland.

Table 4. Estimated production cost of different production systems in the alpine region of the Tibetan Plateau (per hectare). (Source: Dong et al., 2007)

Input and output	Native grassland	Forage oat	Perennial grass monoculture		Perennial grass mixture	
			SW	DW	SB + SW + CW	SB + SW + DW + CW
Operating expenses						
Fertilizer (US$ ha^{-1})	34.5	75	43.5	43.5	43.5	43.5
Seed (US$ ha^{-1})	0	51.75	0	0	0	0
Herbicide (US$ ha^{-1})	0	7.35	2.76	2.76	2.76	2.76
Pesticide (US$ ha^{-1})	3.45	3.45	3.45	3.45	3.45	3.45
Labor (US$ ha^{-1})*	14.62	70.52	21.5	21.5	21.5	21.5
Interest (US$ ha^{-1})**	0.85	3.82	1.03	1.03	1.03	1.03
Total operating expenses (US$ ha^{-1})	53.42	211.89	72.24	72.24	72.24	72.24
Allocated overhead						
Land rent (US$ ha^{-1})	34.5	50	34.5	34.5	34.5	34.5
Establishment/reseeding costs (US$ ha^{-1})	31.02	0	19.10	28.72	31.04	33.72
Total costs (US$ ha^{-1})	118.94	261.89	125.84	135.46	137.78	140.461
Total output						
Hay production (US$ ha^{-1})	338.35	20.78	562.5	531	553.5	558
Economic benefit						
Output/input ratio	2.84	2.16	4.47	3.91	4.02	3.97
Net profit (US$ ha^{-1})	219.41	305.11	436.66	395.54	415.72	417.54

SB, Smooth brome grass; SW, Siberian wild ryegrass; DW, drooping wild ryegrass; CW, crested wheatgrass; FO, forage oat; AR, annual ryegrass. * Sum for human labor and draught power. **Average interest rate was 4.7%. The measurements are means from 1999 to 2003. (Source: Dong et al., 2007)

from replanting activities were surveyed to testify the sustainability of these restoration interventions. Output/input ratios (income: cost) and net profit (income: cost) were used to compare the recovery rate of investment in establishing cultivated perennial grasslands with maintaining native rangeland and planting of an annual forage crop (oat) (Table 4). It was found that perennial grass monocultures of Siberian wild ryegrass (*Elymus sibiricus*) and drooping wild ryegrass (*Elymus nutans*), perennial grass mixtures of smooth bromegrass (SB) + Siberian wild ryegrass (SW) + crested wheat grass (CW, *Agropyron cristatum*) and smooth brome grass (SB, *Bromus inermis*) + Siberian wild ryegrass (SW) + drooping wild ryegrass (DM) + crested wheatgrass (CW) had a higher total revenue/output than the native rangeland and annual forage crop of oat due to their higher production of dry matter. Both perennial grass monocultures and perennial grass mixtures were much higher in the recovery rate of investment (with an output/input ratio of over 4:1) than the rangeland and annual forage crop of oat (with an output/input ratio of below 3:1). Siberian wild ryegrass, SB + SW + DW +CW, SB + SW + CW, drooping wildryegrass, forage oat and native rangeland varied from the highest to the lowest in net profit, in the order of 436.66, 417.54, 415.72, 395.54, 305.11 and 219.41 US$ ha^{-1}. This implies that economic benefits from replanting degraded rangeland with different perennial grass monocultures and mixtures were quite considerable and these restoration interventions might be good income-generation activities for local farmers. The values of soil erosion control was measured to compare the ecological services of replanted

Table 5. Ecological values of different land use systems in the alpine region of the Tibetan Plateau. (Source: Dong et al., 2002).

Land use system	Soil loss or sink (t/hm^2)	Decrement or increment of soil nutrient (kg/hm^2)						
		Organic matter	Nitrogen	Phosphorus	Potassium	Available nitrogen	Available phosphorus	Available potassium
Protected native rangeland	+2.7	+331.6	+26.7	+1.9	+50.0	+0.2	+0.04	+0.5
Grazed native rangeland	-1.4	-171.9	-14.1	-1.0	-25.9	-0.1	-0.002	-0.3
Naturally-restored rangeland	-50.4	-5892	-488.9	-45.3	-932.4	-4.9	-0.08	-9.3
Cultivated perennial grassland	-4.1	-412.9	-36.5	-2.5	-75.9	-0.3	-0.006	-0.8
Annual cropland	-15.4	-1301.3	-129.4	-9.2	-284.9	-0.8	-0.02	-2.8

+ = Deposit; – = loss.

grassland with native rangeland and annual forage crop of oat, as soil erosion was a common problem in the "black-beach" degraded rangeland on the Qinghai-Tibetan Plateau (Table 5). It was found from the investigation that protected native rangeland, regarded as the reference, can sink 2.7 t/hm^2 of soil resource escaping from other regions annually and thus played an important role in conserving soil resources and maintaining soil fertility. Similar to waste land, annual cropland heavily lost soil resources (around 50.4 t/hm^2) and soil fertilities (5892 t/hm^2 of organic matter, 488.9 t/hm^2 of nitrogen, 45.3 t/hm^2 of phosphorus and 932.4 t/hm^2 of potassium) during the half-year rest period in winter due to low vegetation cover and root assembly of primary alpine plants such as *Kobresia* spp., and *Poa* spp., which have evolved high potentials for controlling soil erosion and high feed value for feeding local grazers on the Qinghai-Tibetan Plateau in history. Compared to naturally-restored rangeland, cultivated perennial grassland can reduce 46.3 t/hm^2 of soil erosion annually and lower soil fertility dramatically. As far as ecological values of soil erosion control is concerned, perennial pastures were comparable to grazed native rangeland, which was extensively used by local livestock of yak and Tibetan sheep.

CONCLUSION AND MANAGEMENT IMPLICATIONS

Although it is possible for restoration to occur naturally without human intervention in some circumstances (Berger, 1993), the present results suggest that this is unlikely to happen with "black-beach" degraded rangeland in fragile and severe environments of the headwater areas on the Qinghai-Tibetan Plateau. Many studies along these lines carried out in the Qinghai-Tibetan Plateau (Li, 1992; Li et al., 1993; Li and Huang, 1995) and other alpine areas like the Alps (Urbanska, 1994; 1995; Urbanska and Fattorini, 2000) show the slowness and irregularity of rangeland self-recovery in such an environment. Considering the fact that different levels of degradation in grassland and meadow influence the choice of interventions required (Bradshaw, 1992), it is imperative in choosing the restoration interventions to follow the principles proposed by Aronson et al. (1993) and Muller et al. (2003):

(1) low degradation levels should permit passive restoration; (2) a more important degradation level makes necessary more active intervention aimed at the recovery of functionally similar ecosystem by a rehabilitation (such as reseeding) process, which can lead to a transitional ecosystem that will then more or less quickly evolve towards the "alternative steady-state", corresponding to the ecosystem present before human perturbation; (3) if one or more thresholds of irreversibility of degradation have been crossed, a reallocation can be attempted in order to create a new and different kind of grassland ecosystem (such as cultivated grassland).

According to this baseline, rehabilitation (reseeding) and reallocation (establishing cultivated grassland) are needed to restore the "black-beach" type degraded rangelands at the headwater areas of the Qinghai-Tibetan Plateau. From this context, the inference can be drawn that design theory is more applicable than self-design theory in guiding the restoration interventions for "black-beach" degraded rangeland at the headwater areas of the Qinghai-Tibetan Plateau.

When the design theory was practically applied in guiding the restoration interventions, different principles were proposed by different researchers for different ecosystems. For example, Mitsch (1992) presented eight principles for wetland design; Jørgensen and Neilsen (1996) proposed 12 principles for ecological applications to agriculture while Zalewski (2000) identified three principles for the study of ecohydrology. Combing the ideas from this study with ideas from other researchers who had used the design theory guiding alpine rangeland restoration practices, four major principles for designing alpine rangeland restoration were summarized as follows: (1) design consistent with ecological principles; (2) design for site-specific context; (3) maintain the independence of design functional requirements; and (4) acknowledge the values and purposes that motivate design.

In this study, design theory to replant the “black-beach” degraded rangeland with native grasses such as smooth bromegrass and their mixtures was applied by following the ecological principles of species adaptation, niche separation and community succession, etc. Moreover, when designing the restoration actions, not only the ecological services of the restored rangeland reflected by ecological values at the headwater areas of Qinghai-Tibtean Plateau was considered, but also the productive functions reflected by economic values in the context of Tibetan pastoral society. This study might provide a good example for setting appropriate principles of design theory in alpine rangeland ecosystem restoration projects.

Despite the fact that replanting directed by the design theory can improve vegetation condition and ecological values to some extent, the rangeland ecosystem cannot be considered truly restored, since merely recreating the physical form or appearance of an ecosystem without restoring its naturally occurring ecological functions does not constitute complete restoration (Berger, 1993). For management purposes, a decision must be made as to whether the alternative state is acceptable, or whether a true restoration is desired. The impacts of restoration practices on ecological functions and economic values need to be taken into consideration in making management plans for improving the sustainable development of the alpine rangeland at the headwater areas of Qinghai-Tibetan Plateau (Dong et al., 2007). Rapid reconstitution of the vegetation is desirable as much for landscape quality as for erosion control and leads to the constitution of cultivated grassland (Dong et al., 2002), an ecosystem of substitution, which can progressively be replaced by native plant communities according to the observations in this study. As early signs of restoration success are often recognizable in the population process and not in a full recovery of soil or vegetation (Urbanska 1998), seed rain, seed bank and seedling germination should be included in post-restoration monitoring and assessment of restoration practices at the headwater areas of Qinghai-Tibetan Plateau and need to be stressed in further studies.

ACKNOWLEDGMENT

This study is supported by Projects from National Science Foundation of China (30870466, 50939001). The authors wish to express deep thanks to reviewers and editors for their time and efforts.

REFERENCES

Aronson J, Floret C, Le Floch E, Ovalle C, Pontanier R (1993). Restoration and rehabilitation of degraded ecosystems in arid and semi-arid lands. I. A view from the south. Restoration Ecol., 1: 8-17.

Bradshaw AD (1992). The biology of land restoration. Pages 25-44 in S.K. Jain and L.W. Botsford, etiors. Applied population biology. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Bradshaw AD (1987). The reclamation of derelict land and the ecology of ecosystems. Pages 53-74 in W.R. Jordan, III, M.E. Gilpin, and I.D. Aber, editors. Restoration Ecology. Cambridge University Press, Cambridge, United Kingdom.

Bradshaw AD, Handley J (1982). An ecological approach to landscape design: principles and problems. Landscape Design, 138: 30-34.

Dong SC, ZhouCJ, Wang HY (2002). Ecological crisis and countermeasures of the Three Rivers' headstream regions. J. Nat. Res., 17(6): 713-720.

Dong SK, Gao HW, XU GC, Hou XY, Long RJ, Kang MY, Lassoie PJ (2007). Farmer and professional attitudes to the large-scale ban on livestock grazing of grasslands in China. Environ. Conserv., 34(3): 246-254.

Dong SK, Hu ZZ, Long RJ, Kang MY, Jiang Y (2002). Effect of Mixture Perennial Grass on the Vegetation and Soil of Grassland and the Economic Values of Mixture Grassland in Alpine Region. J. Soil Erosion Control, 13(3): 98-101.

Dong SK, Kang MY, Long RJ, Yun XJ, Hu ZZ (2007). Economic comparison of annual crop, perennial pasture and native grassland forage production in the alpine region of the Qinghai-Tibetan Plateau, China. Grass Forage Sci., 62: 405–415.

Du MY, Kawashima S, Yonemura S, Zhang XZ, Chen SB (2004). Mutual influence between human activities and climate change in the Tibetan Plateau during recent years. Global Planetary Change, 41: 241-249.

Jørgensen SE, Neilsen SN (1996). Application of ecological engineering principles to agriculture. Ecol. Eng., 7: 373-381.

Lan YR (2004). The degradation problem and strategy of alpine meadow in Qinghai-Tibetan Plateau. Qinghai Prataculture, 13(1): 27-30.

Li FJ, Sun BS, Li XL (1993). Experimental study on controlling “Black-beach” degraded grassland. Qinghai Prataculture. 4(1): 33-35.

Li XL (1992). Variation of plant biomass from fencing “Black-beach” degraded grassland. Qinghai Prataculture, 3(3): 20-24.

Li XL, Huang BN (1995). The cause of “Black Beach” degraded grassland and its control measures. Grassland China, 4: 64-67.

Ma YS, Lang BN, Li QY, Li YF, Li FJ (1999). The present status of the grassland eco-environment at the headwater areas of Qinghai-Tibetan Plateau and resume strategies of degraded grassland. Grassland China, 6: 59-61.

Ma YS, Lang BN, Li QY, Shi JJ, Dong QM (2002). Study on rehabilitation technologies for degenerated alpine meadow in the Changjiang and Yellow river source region. Pratacultural Sci., 19 (9): 1-5.

Ma YS, Shang ZH, Shi JJ, Dong QM, Wang YL, Yang SH (2006). Studies on communities diversity and their structure of “black-soil-land” degraded grassland in the headwater of Yellow River. Pratacultural Sci., 23(12): 6-11.

Middleton B (1999). Wetland restoration, flood pulsing, and disturbance dynamics. John Wiley & Sons, Inc., New York.

Mitsch WJ (1992). Landscape design and the role of created, restored, and natural riparian wetlands in controlling nonpoint source pollution. Ecol. Eng., 1: 27-47.

Muller S, Dutoit T, Alard D, Grévilliot F (2003). Restoration and Rehabilitation of species-rich grassland ecosystems in France: a review. Restoration Ecol., 6(1): 94-111.

Shang ZH, Long RJ (2005). Formation reason and recovering problem of the “black soil type” degraded alpine grassland in Qinghai-Tibetan Plateau. Chinese J. Ecol., 24(6): 652-656.

Urbanska KM (1994). Ecological restoration above the timberline:

demographic monitoring of whole trial plots in the Swiss Alps. Botanica Helvetica, 104: 141-156.
Urbanska KM (1995). Biodiversity assessment in ecological restoration above timberline. Biodiversity Conserv., 4: 679-695.
Urbanska KM, Fattorini M (2000). Seed rain in high-altitude restoration plots in Switzerland. Restoration Ecol., 8(1): 74-79.
Wang GX, Cheng GD (2001). Characteristics of Grassland and Ecolo cal Changes of Vegetations in the Source Regions of Yangtze and Yellow Rivers. J. Desert Res., 21(2): 101-107.
Wang GX, Wang YB, Qian J, Wu QB (2006). Land Cover Change and Its Impacts on Soil C and N in Two Watersheds in the Center of the Qinghai-Tibetan Plateau. Mountain Res. Dev., 26(2): 153-162
Zalewski M (2000). Ecohydrology — the scientific background to use ecosystem properties as management tools toward sustainability of water resources. Ecol. Eng., 16:1-8.
Zedler JB (2000). Progress in wetland restoration ecology. Tree, 1(10): 402-407.