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RESPONSE OF *HALOXYLON AMMODENDRON* (C. A. MEY) TO UNDERGROUND WATER QUALITY, DEPTH AND SOIL SALT DEPOSITION IN GURBANTONGGUT DESERT, WEST CHINA

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Abstract

Haloxylon ammodendron degradation in arid regions of China has become a serious and widespread ecological issue. This study attempts to provide theoretical support for achieving the goal of ecological protection and construction as well as its restoration and reconstruction in the desert regions. A three-year research of the groundwater under the western hinterland of Junggar basin in Xinjiang was carried out to analyse groundwater depth, its water quality, soil physicochemical properties and some other characteristics in areas of *H. ammodendron* degradation. The results reveals that species richness in the region is not directly connected with groundwater level, but negatively correlated with soil conductivity. The research further investigated that groundwater level has no significant effect on the survival of *H. ammodendron* seedlings. However, there exists a significantly positive correlation between the mortality rate of *H. ammodendron* seedlings and soil conductivity. The growth of *H. ammodendron* in the degraded area is affected by both groundwater level and its water quality. Surface soil salt deposition leads to a physiological water shortage of *H. ammodendron* seedlings, and affected regeneration of seedlings. The coverage and decline rates of *H. ammodendron* have a quadratic function relation with groundwater respectively and in a linear correlation with the soil surface conductivity. The results concluded decline of groundwater level. Its degree of mineralization and soil surface salinization are three dominant factors in this region of *H. ammodendron* degradation.

Key words: Gurbantonggut desert of China; Vegetation degradation; *H. ammodendron*; Groundwater level; Water quality; Soil salt deposition.

Introduction

Vegetation degradation has become one of the worldwide ecological concerns in recent years. The drought caused by climate changes led to a large number of deaths of *Scots pine* and *Pinus pondero*sa (Bigler *et al.*, 2006; Mcdowell *et al.*, 2008; Reich & Oleksyn, 2008). Changes in land use patterns, temperature changes, drying rivers and falling underground water level caused vegetation degradation in parts of the world (Kakembo, 2001; Xu *et al.*, 2003; Zhang *et al.*, 2006).Vegetation degradation can lead to regional energy imbalance, land desertification, salinization, changes of soil physical properties and the carbon cycle (Xu *et al.*, 2002; Wang *et al.*, 2007; Hu *et al.*, 2009). The earth's physical and biological environment changes caused by natural and man-made factors have profound influences on human's living environment. For example, the changes of land water resources and water cycle (Oki & Kanae, 2006; Koepke *et al.*, 2010; Shen & Chen, 2010) greatly affect the natural vegetation in arid areas. Underground water is an important part of water resources, affecting the ecological environment of earth surface in terms of time and space directly or indirectly. It affects the growth of natural vegetation directly and plays an irreplaceable role in biodiversity conservation in arid areas and ecosystem stability (Elmore *et al.*, 2006; Mclendon *et al.*, 2008; Hao *et al.*, 2009).

The natural rainfall cannot meet the normal demand of plant growth in northwest arid areas of China (Li *et al.*, 2002; Zhao & Liu, 2006). In such conditions underground water becomes a key resource for the plant (Rodriguez-Iturbe, 2000; Guo & Liu, 2005; Fan, 2008). Such areas exist a mixed landscape of mountain, plains and basins. As a result, surface water and groundwater comes primarily from the precipitation in mountainous areas. There is necessarily a strong connection between groundwater changes in the downstream and basin areas and water utilization in upstream areas (Xia *et al.*, 2003; Elmore *et al.*, 2003; Liu *et al.*, 2010).

Junggar Basin- in China is the second largest basin, located in northern Xinjiang Uygur Autonomous Region surrounded by Tianshan mountains, Tal Bach mountains and Altai mountains. In the middle of the basin is China's second largest desert-Gurbantonggut desert. The rivers which originate from mountains are supplied by glaciers and snowmelt water flow through the alluvial plains and finally into the basin. Since 1970s, the human activities have significantly changed the natural water cycle pattern of Junggar basin. For example, the Manas river dried up, the ground water level of oasis area went down and the sizes of Manas lake, Eric lake as well as Wulungu lake in the central basin declined year by year (Cheng *et al.*, 2005).

H. ammodendron is the constructive species of vegetation (Huang *et al.*, 2009) in Gurbantonggut desert. It is very important for the protection of the ecological environment.It is mainly found in the northwest of China. Its distribution in Xinjiang accounts for 68% of total in China. Its distribution in Junggar Basin accounts for 94% of that in Xinjiang. In recent years, we have found that the vegetation coverage in the western plains of Gurbantonggut desert in the west of the basin has decreased while community edificators- *H. ammodendron* degraded in a lot of areas, amounting to 40,000 kilometer square Also, species regeneration was inhibited while serious erosion in some areas near Karamay has emerged. This area is one of the sources of sandstorms in northern Xinjiang (Qian *et al.*, 2005), therefore it is extremely necessary to analyze the causes of vegetation death, probe into vegetation degradation mechanisms, adopt effective ways to reduce and curb vegetation degradation and put forward scientific and reasonable methods of vegetation restoration.

Currently, research of the death and degradation of *H. ammodendron* is mainly conducted in Inner Mongolia Autonomous Region and Gansu province of China. The main reasons of *H. ammodendron* forest degradation are soil moisture, planting density and a sharp decline in groundwater level caused by excessive human exploitation of water resources (Yang, 1991; Han *et al.*, 2001; Han *et al.*, 2002; Wang & Ma, 2003). However, the study of *H. ammodendron* degradation and death in Gurbantonggut desert is rarely reported and not mentioned in any comprehensive and integrated studies on *H. ammodendron* degradation.

The oasis region in the peripheral edge of Junggar basin was hit by the heaviest-ever rainfall in 50 years from December, 2009 to March, 2010, with its amount increasing 1.5 times year after year. Manas river basin suffered from a heavy flood in the summer of 2010 (Zeng, 2010). As a result, the once dried up Manas river released more flood waters downstream than previous years. What effect does this special event have on the groundwater level of Junggar basin? What kind of relationship exists between the upstream agricultural water and groundwater under the basin? Are changes of groundwater level and water quality associated with vegetation degradation? All the issues above need to be studied. Based on a three-year research of the groundwater under the western hinterland of Junggar basin from 2008 to 2010 and combined with an analysis of water delivery changes of the upstream Manas river, this thesis attempts to analyze the relationship between changes of upstream surface water and groundwater level as well as water quality in the basin, probe into the influence of groundwater level changes on species diversity, make a comparative analysis of groundwater depth, soil physicochemical properties and other characteristics in regions with different level of *H. ammodendron* degradation, and finally explore the causes of degradation and death of natural *H. ammodendron* forest in Gurbantonggut desert in an attempt to provide a theoretical reference for ecological restoration of degraded *H. ammodendron* forest.

Material and Methods

The study area and climate data in the study area: The study area is located in the west of Gurbantonggut desert of the Junggar basin hinterland as well as the lake-basin zone of old Manas lake (Chen *et al.*, 2001), and the new Manas lake to its south. Its geographic position is 45° 09'N-45° 40'N, 85° 10'E-86° 45'E (Fig. 2). With a typical temperate arid desert climate, its summer is hot and its winter is cold. Its average annual rainfall is less than 80 mm and its average annual evaporation is more than 3600 mm. In June and July, the average temperature is above 27^{o}C, and the absolute maximum temperature is above 44^{o}C. In January, the average temperature is below -19^{o}C, and the absolute minimum temperature is below -43^{o}C. The past decade witnessed a small amount of rainfall in this region, which is significantly different from regions on the periphery of the desert such as Mossel bay region, Karamay region and Bukesaier region which saw a trend of increasing amount of rainfall (Yin, 1993).

Most of the research area is low-lying land caused by runoffs and ancient lake (river) facies zone. As the water evaporated, a layer of physical crust formed on the soil surface. The salt accumulation on the surface is so serious that a hard layer of salt crust formed with a high level of salinization (Liu *et al.*, 2010). Most of the soil is cracking salt clay with some sandy loam. As the plant diversity is not quite great, we found 26 species, most of which are xeric with salt-tolerant characteristics except few ephemeral plants. *H. ammodendron* is the dominant species. There is a small amount of *Anabasis aphylla*, *Calligonum leucocladum* as well as brown-winged *Salsola korshinakyi*. There are also Herbaceous plants including sharp-leaves *Kalidium cuspidatum*, pointe-wing *Kochia odontoptera*, *Atriplex dimorphostegia*, *Zygophyllum fabago* and so on.

Global climate change could lead to an increase of the drought frequency in some areas, which could have a huge impact on the local vegetation. As meteorological stations are not found in desert hinterland, this study uses meteorological data from the German Global Precipitation Climate Center (GPCC). Adopting the precipitation data from 1951 to 2008 with an accuracy of 0.5 ° × 0.5 ° and the temperature data from 1999 to 2009 in the study area and using interpolation, we obtained meteorological data with an accuracy of 0.1°× 0.1°, which would then be corrected using the measured data from nearby weather stations. With a reference to Nix (Nix, 1986), we obtained the annual precipitation (Pann), annual average temperature (Tann) and potential evapotranspiration (PET, PET=BT×58.93).

$$BT = \sum_{i=1}^{12} \left(T_i / 12 \right)$$

where, *BT* refers to the annual average temperature, while T_i means less than the average temperature of 50^{o}C.

The irrigation conditions of Oasis Agricultural in Manas river valley: Cotton is the main crop in Corps (an area with Chinese characteristics), villages and towns of Manas river basin, accounting for 68% to 72% of the total cropped area (Statistics Bureau of XPCG and the Survey Office of XPCG of NBS, 2009; Statistics Bureau of XPCG and the Survey Office of XPCG of NBS, 2010). With an adjustment of crop structure in 2009 and 2010, the wheat area increased, accounting for only 11.9%. Based on the amount of water diverted from the upstream of Jingou river in the Manas river basin, the largest irrigation amount occurs in July, and the water utilization is at peak from June to August (Fig. 1). The irrigation time of winter wheat occurs at the end of October and November, which leads to the second water utilization time at peak. Manas river suffered from the heaviest ever flood once in a decade from July to August, 2010(Fig. 1), which resulted in a large water area and a serious damage to crops in an area of 18.744 km^2(we introduced the flood in 2010,the blood was connected with underground water here).

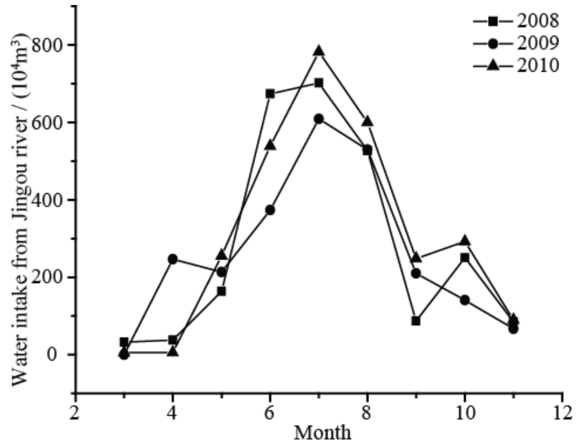

Fig. 1. Changes of water intake from Jingou river in each month.

Observation of groundwater level, samples options and vegetation survey: According to the degradation and distribution of *H. ammodendron* in western Gurbantünggüt desert, we built 20 wells for groundwater level observation every 7-10 km along the longitude direction and latitude direction. The area we covered include different habitats, such as plain and small dune (height<5 m). It is nearly 130 km long and nearly 80 km wide (Fig. 2). We observed groundwater level and collected water samples to analysis the quality of groundwater every month using clock-measuring method from January, 2008 to December, 2010.

In June and July, during years from 2008 to 2010, we set 20 sample plots (number 1～20 (Fig. 2) of 50 m × 50 m near those observation wells, and divided each sample plot into 25 small quadrats of 10 m × 10 m using an adjacent grid method to conduct a vegetation survey. Our survey deals with (1) the species, number, height and ground diameter in each quadrat;(2) the number of living and dead *H. ammodendron* plants and plants crown; (3) the number of regeneration and survival of *H. ammodendron* seedlings. We measure their growth using living index (the ratio of the numbers of live plants and dead plants of *H. ammodendron*) in sample plots. Indicators of vegetation analysis included Gleason richness index as well as the cover degree, fading rate (the ratio of plant number with 50% deadwood or more and the total plant number) and seedlings mortality of *H. ammodendron*.

Age structure, distribution characteristics of *H. ammodendron* population and soil electrical conductivity of degradaded area: For *H. ammodendron*, it is difficult to infer their age from the annual ring due to their irregular growth. As the height of *H. ammodendron*. has a strong correlation (R^2 = 0.6351, p<0.001) with aboveground diameter (Huang *et al.*, 2008), we used plant height with a hope to analyze the age characteristics of *H. ammodendron* population. we divided these *H. ammodendron* plants into six age classes I ~VI from the youngest to the oldest, and attempted to reveal the percentage of live *H. ammodendron* plants of different age classes in each sample plot in all *H. ammodendron* plants and then build the age class (Fig. 5).

We studied the distribution pattern of *H. ammodendron* by using the variance mean ratio V/M (Zhang, 2004), to analyze whether *H. ammodendron* plants died within species self-thinning with t-test (Species self-thinning is a population distribution which is either random distribution or uniform distribution). Calculated as follows:

$$V= [\sum X^2-(\sum X)^2/N]/(N-1) \quad (1)$$
$$M= \sum X/N \quad (2)$$

where, V represents variance; M represents the mean; X is the number of dead *H. ammodendron* in quadrats; N = 25, means the number of quadrats divided in each sample plot. If V/M = 1, the population distribution of *H. ammodendron* in the degradation area is a random one; If V/M > 1, it is a cluster distribution; If V/M < 1, it is a uniform distribution.

After randomly selecting four collection points in each of the 20 sample plots. we collected soil from 0 ~ 40 cm, 40-80 cm and 80 ~ 120 cm layers (a total of 4 × 3 × 20 = 240 soil samples), and measured the soil electrical conductivity (EC) in the laboratory.

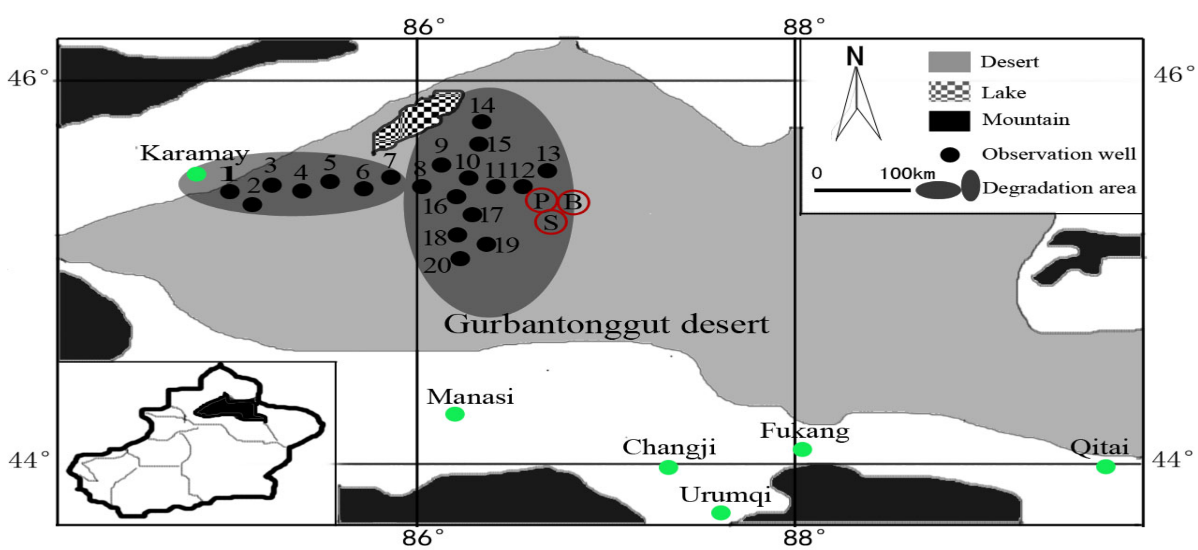

Fig. 2. Distribution of gurbantunggut desert and sampling locations.

Data processing: We used SPSS17.0 software for the statistical analysis (SPSS, Inc., Chicago, IL, USA). The distribution type of *H. ammodendron* in degradation area and temporal changes of groundwater level in 20 groundwater monitoring wells were calculated using descriptive of SPSS (Tables 1 & 2). Regression coefficients of the relationship between groundwater level, soil conductivity and species richness, rate of decline, coverage, rate of seedling mortality of *H. ammodendron wrere tested using* analysis of regression at the 99% confidence interval or the 95% confidence interval (Table 3). The mapping softwares were Origin 8.6 (Fig. 1, Figs. 3-7) and Auto CAD2007, Photoshop CS8.0 (Fig. 2).

Table 1. The distribution type of *H. ammodendron* in degradation area.

Plots	v/m	Distribute type	Plots	v/m	Distribute type
1	1.92*	C	11	7.70**	C
2	1.09	C	12	6.77**	C
3	3.61**	C	13	1.89	C*
4	1.01	C	14	5.79**	C
5	2.33*	C	15	1.00	R
6	2.76**	C	16	2.03	C*
7	4.72**	C	17	2.31	C*
8	5.85**	C	18	5.92**	C
9	1.91*	C	19	0.31	U
10	2.35*	C	20	1.90*	C

Asterisk express the significantly of the mass, one asterisk express $p<0.05$, two asterisks express $p<0.01$; C: Clumped distribution, R: Random distribution, U: Uniform distribution

Results

Precipitation, annual temperature (Tann) and potential evapotranspiration (PET,PET=BT×58.93) in the study area: According to a GPCC's differential analysis of the precipitation data in the region from 1950 to 2008 (Fig. 3), precipitation changed from 60 to 200 mm, mainly from 90 to160 mm. As there did not exist a continuous wet or dry weather condition, there was not an obvious trend of drought. At the same time, since there was not an intense precipitation fluctuation, it was not the cause of large-scale death of *H. ammodendron*.

Figure 4 shows that the annual average temperature and possible evapotranspiration both have a trend of slight but not obvious increase. The study area does not see extreme weathers of continuous low or high temperatures, indicating that *H. ammodendron* degradation is not obviously related to annual average temperature and potential evapotranspiration.

Distribution characteristics and age structure of degradated of dead *H. ammodendron*: *H. ammodendron* population is distributed evenly or randomly when in a natural state (Li *et al.*, 2003). We found significant ($p<0.05$) or highly significant ($p<0.01$) distribution clusters in 16 of the 20 sample plots located in the plains and small dunes of areas of *H. ammodendron* degradation. Among the rest are a random distribution cluster, a even distribution cluster and two plots without any significant distribution. ($p>0.05$). The result showed that the death is not caused by self-thinning. On the contrary, the death of *H. ammodendron* plants occurred in clusters (Table 1).

There is a certain proportion of *H. ammodendron* sprouts in P1, P2, P5, P10, P15 and P16 of Fig. 5, which suggests the population is growing. However, there is a serious scarcity of sprouts in other sample plots, indicating a poor capability of population regeneration. We also found that *H. ammodendron* plants of each age class were dying in Fig. 5 without any obvious regularities, indicating little relevance between *H. ammodendron* degradation and plants age.

Temporal and spatial variations of groundwater level and physical and chemical characteristics of soil in the study area: We found that the groundwater level changed greatly in different sample plots in the plains and dunes of the research area in Table 2, ranging from 3.3 m to 24.2 m. Most of the water level of observation wells is 6-8 m. Each year, groundwater level of each sample plot fluctuate frequently. The maximum depth of water level of 80% observation wells appear in July, while 20% from August to November. The minimum depth comes in April.

Groundwater level change significantly in different years. Compared to the previous year, the water depth of observation wells rose by 1 cm-11 cm in 2010. There was a trend of gradual rising mineralization from 2008 to 2010 (Fig. 6). The mineralization level of two observation wells near the unnamed lake of the Manas River reached up to 20 g / L or more (P1, P2), which was much higher than those of other observation wells.

As can be seen from Fig. 7, the average of all soil indicators is high in 0-40 cm soil. It's quite different in the same solum of different sample plots. The variation coefficients of all indicators except pH value are more than 10%, and a few of them are more than 100%. The variation coefficients of soil conductivity, pH value, Cl^- and SO_4^{2-} in 0-40 cm solum are bigger than those in other solum, indicating that the variability of soil salinity decreases as soil depth increases in the vertical direction. There is a big difference in different sample plots in the horizontal direction, indicating a great spatial variability.

The impacts of water and salt changes on *H. ammodendron*: The study found that vegetation constituttion lacks diversity in degraded areas where *H. ammodendron* and *Salsola collina* are the main vegetation with *Tamarix chinensis* and *Calligonum mongolicum* in some sample plots. There is not a linear relationship between the annual species richness index and groundwater level (Table 3). There is a significant negative correlation between species richness and soil conductivity (Table 3), since species richness decreases when the conductivity increases, indicating that the soil salt accumulation is an important reason for hindering species richness in degraded areas.

The growth of *H. ammodendron* is affected by both the groundwater level and soil conductivity. Its coverage and decline rate have a quadratic linear correlation with groundwater level respectively (Table 3). According to the properties of the linear quadratic, *H. ammodendron* coverage is generally high and the recession rate is low when the groundwater level is 5-8m. When the groundwater level is 3-5 m or 8-11 m**,** the growth of *H. ammodendron* is hindered. There is a significant negative correlation ($R^2 = 0.40377$, $P = 0.00155$) between *H. ammodendron* coverage and soil conductivity of 0-40 cm solum, while there is a significant positive correlation ($R^2 = 0.61246$, $p<0.001$) between the rate of decline and soil conductivity of 0-40 cm, indicating that the increase of soil surface conductivity adversely affects the growth of *H. ammodendron* while reducing population coverage and increasing the decline rate.

Table 2. Temporal changes of groundwater level in 20 groundwater monitoring wells.

Month	Groundwater level/m(Mean±SE) /m				
	P1	**P2**	**P3**	**P4**	**P5**
1	-7.5137 ± 0.02739	-11.0233 ± 0.05364	-7.4767 ± 0.10729	-3.3333 ± 0.00667	-5.2867 ± 0.00667
2	-7.5077 ± 0.01534	-10.9967 ± 0.04055	-7.48 ± 0.11533	-3.3367 ± 0.00882	-5.2733 ± 0.00882
3	-7.5007 ± 0.02557	-10.9833 ± 0.04096	-7.47 ± 0.10017	-3.33 ± 0.00577	-5.27 ± 0.01
4	-7.4867 ± 0.02963	-10.9733 ± 0.03528	-7.4333 ± 0.10868	-3.3133 ± 0.00882	-5.2517 ± 0.00441
5	-7.5073 ± 0.02876	-11.0033 ± 0.01453	-7.4733 ± 0.14345	-3.3367 ± 0.01453	-5.29 ± 0
6	-7.5317 ± 0.01167	-11.0767 ± 0.0318	-7.5 ± 0.14572	-3.3567 ± 0.00333	-5.3167 ± 0.00333
7	-7.555 ± 0.02843	-11.13 ± 0.01732	-7.5867 ± 0.11552	-3.37 ± 0	-5.3867 ± 0.00882
8	-7.5267 ± 0.02333	-11.0567 ± 0.02333	-7.5733 ± 0.11977	-3.34 ± 0.01528	-5.3733 ± 0.01453
9	-7.5183 ± 0.02205	-11.0417 ± 0.03678	-7.5767 ± 0.1099	-3.3267 ± 0.02186	-5.3717 ± 0.01691
10	-7.54 ± 0.05508	-11.0033 ± 0.06741	-7.5633 ± 0.11865	-3.3133 ± 0.01667	-5.32 ± 0.01528
11	-7.5467 ± 0.0584	-11 ± 0.07638	-7.5567 ± 0.11141	-3.32 ± 0.00577	-5.3067 ± 0.00882
12	-7.5533 ± 0.05239	-10.9967 ± 0.05696	-7.5733 ± 0.1217	-3.3233 ± 0.00333	-5.2933 ± 0.00882
	P6	**P7**	**P8**	**P9**	**P10**
1	-4.8033 ± 0.03844	-6.6767 ± 0.02728	-3.73 ± 0.01155	-8.9867 ± 0.02667	-6.7667 ± 0.02028
2	-4.81 ± 0.03055	-6.6767 ± 0.02404	-3.7333 ± 0.01333	-9.0033 ± 0.03333	-6.75 ± 0.01528
3	-4.7967 ± 0.02028	-6.67 ± 0.02082	-3.7367 ± 0.00882	-8.98 ± 0.02887	-6.7333 ± 0.00882
4	-4.7833 ± 0.0318	-6.6583 ± 0.01878	-3.7283 ± 0.02048	-8.95 ± 0.00577	-6.7217 ± 0.00601
5	-4.7967 ± 0.0348	-6.68 ± 0.01732	-3.74 ± 0	-8.9667 ± 0.00333	-6.7433 ± 0.02906
6	-4.8067 ± 0.0348	-6.7067 ± 0.01856	-3.75 ± 0.00577	-8.9833 ± 0.02028	-6.7767 ± 0.02963
7	-4.85 ± 0.03786	-6.7267 ± 0.0318	-3.7733 ± 0.01202	-9.06 ± 0.02082	-6.8233 ± 0.03844
8	-4.8167 ± 0.05239	-6.71 ± 0.02646	-3.7433 ± 0.00882	-9.0633 ± 0.03383	-6.8267 ± 0.02333
9	-4.8083 ± 0.04324	-6.7133 ± 0.01453	-3.7317 ± 0.01691	-9.0483 ± 0.01833	-6.8317 ± 0.02167
10	-4.795 ± 0.04481	-6.715 ± 0.01756	-3.74 ± 0.01732	-9.0383 ± 0.0159	-6.79 ± 0.01
11	-4.8233 ± 0.05364	-6.7167 ± 0.01453	-3.7567 ± 0.01764	-9.0333 ± 0.01202	-6.7733 ± 0.02404
12	-4.8067 ± 0.04333	-6.7067 ± 0.01453	-3.7533 ± 0.01202	-9.0067 ± 0.02848	-6.7633 ± 0.02603
	P11	**P12**	**P13**	**P14**	**P15**
1	-6.8467 ± 0.00333	-6.7867 ± 0.01856	-7.62 ± 0.00577	-10.4767 ± 0.01202	-24.1767 ± 0.00667
2	-6.8433 ± 0.00333	-6.7833 ± 0.02186	-7.62 ± 0.00577	-10.4767 ± 0.00667	-24.1767 ± 0.00333
3	-6.8333 ± 0.00333	-6.7767 ± 0.01453	-7.61 ± 0	-10.4767 ± 0.00333	-24.1767 ± 0.02028
4	-6.8167 ± 0.00882	-6.7733 ± 0.01856	-7.6033 ± 0.01453	-10.4733 ± 0.00667	-24.17 ± 0.01155
5	-6.8433 ± 0.02028	-6.8033 ± 0.00882	-7.61 ± 0.00577	-10.4833 ± 0.00667	-24.18 ± 0.00577
6	-6.8533 ± 0.02404	-6.8 ± 0.01528	-7.63 ± 0.01	-10.5033 ± 0.00667	-24.2 ± 0.00577
7	-6.88 ± 0.02082	-6.8233 ± 0.0318	-7.65 ± 0.01528	-10.5267 ± 0.00882	-24.2033 ± 0.01202
8	-6.87 ± 0.03512	-6.8167 ± 0.03283	-7.6433 ± 0.01333	-10.5167 ± 0.00882	-24.1933 ± 0.01333
9	-6.835 ± 0.035	-6.7983 ± 0.04045	-7.6217 ± 0.03346	-10.5083 ± 0.02489	-24.18 ± 0.01732
10	-6.82 ± 0.01443	-6.78 ± 0.02	-7.61 ± 0.02517	-10.4867 ± 0.02333	-24.195 ± 0.01041
11	-6.8333 ± 0.02333	-6.7733 ± 0.01667	-7.6067 ± 0.01764	-10.48 ± 0.01	-24.2067 ± 0.02906
12	-6.82 ± 0.02082	-6.7733 ± 0.01202	-7.6033 ± 0.01453	-10.4767 ± 0.00333	-24.1967 ± 0.02906
	P16	**P17**	**P18**	**P19**	**P20**
1	-7.2633 ± 0.00882	-7.7567 ± 0.02404	-6.3633 ± 0.01202	-5.66 ± 0.00577	-6.29 ± 0.02
2	-7.2567 ± 0.00333	-7.75 ± 0.01732	-6.3633 ± 0.00333	-5.6433 ± 0.01453	-6.2867 ± 0.01202
3	-7.25 ± 0.00577	-7.7433 ± 0.01333	-6.3467 ± 0.00333	-5.6267 ± 0.00333	-6.28 ± 0.02082
4	-7.235 ± 0.005	-7.7217 ± 0.01922	-6.3217 ± 0.01014	-5.61 ± 0.02082	-6.2667 ± 0.01453
5	-7.25 ± 0.02	-7.7367 ± 0.00667	-6.3267 ± 0.01764	-5.6143 ± 0.01946	-6.2833 ± 0.00882
6	-7.29 ± 0.00577	-7.77 ± 0.01	-6.3567 ± 0.00667	-5.6233 ± 0.02333	-6.3 ± 0.00577
7	-7.3267 ± 0.00667	-7.8333 ± 0.02186	-6.4167 ± 0.01333	-5.6633 ± 0.01333	-6.3133 ± 0.02028
8	-7.3167 ± 0.02333	-7.8233 ± 0.01764	-6.4067 ± 0.02848	-5.6633 ± 0.01667	-6.2833 ± 0.02028
9	-7.3133 ± 0.00882	-7.83 ± 0.01	-6.4017 ± 0.01302	-5.6717 ± 0.0159	-6.28 ± 0.01732
10	-7.28 ± 0.02082	-7.8267 ± 0.0393	-6.4167 ± 0.03528	-5.675 ± 0.01258	-6.2883 ± 0.01093
11	-7.2733 ± 0.01202	-7.7867 ± 0.04667	-6.39 ± 0.02	-5.66 ± 0.01528	-6.3 ± 0.03055
12	-7.26 ± 0	-7.77 ± 0.04163	-6.37 ± 0.02	-5.6433 ± 0.01202	-6.2933 ± 0.02963

Table 3. Relationship between groundwater level, soil conductivity and species richness, rate of decline, coverage, rate of seedling mortality of *H. ammodendron*.

Relation	Year	Slope	Intercept	R^2	P	Sign		Fitting way
G.L.(X) and S.R.(Y)	2008	-0.00995	1.70862	0.05617	0.83873	-		Linear Y=aX+b
	2009	-0.05285	2.0207	0.01589	0.40844	-		
	2010	-0.03898	2.12644	0.2939	0.49508	-		
S.C.(X) and S.R.(Y)	2008	-2.20307	2.16256	0.42012	0.00119	**		
	2009	-0.27464	2.34313	0.49038	<0.001	**		
	2010	-0.2348	2.43876	0.46157	<0.001	**		
S.C.(X) and R.D.*H.A.*(Y)	2010	6.30908	23.6642	0.61246	<0.001	**		
S.C.(X) and C.*H.A.*(Y)	2010	-1.12138	13.0588	0.40377	0.00155	**		
G.L. (X)and R.S.M.*H.A.*(Y)	2010	-4.76874	91.7475	0.05418	0.1722	-		
S.C.(X) and R.S.M.*H.A.*(Y)	2010	16.18649	18.6891	0.57408	<0.001	**		
		B_1	B_2	Intercept	R^2	P	Sign	
G.L. (X)and R.D.*H.A.*(Y)	2010	-18.96899	1.25058	106.4261	0.35967	0.01102	*	Polynomial $Y=B_1X+B_2X^2+C$
G.L. (X)and C.*H.A.*(Y)	2010	4.34703	-0.30326	-4.29155	0.48231	0.00201	**	

\# G.L.: Groundwater level, S.R.: Species richness, S.C.: Soil conductivity (0 cm-40 cm), R.D. *H.A.*: Rate of decline of *H. ammodendron,* C.*H.A.*: Coverage of *H. ammodendron* R.S.M. *H.A.*: Rate of seedling mortality of *H. ammodendron*

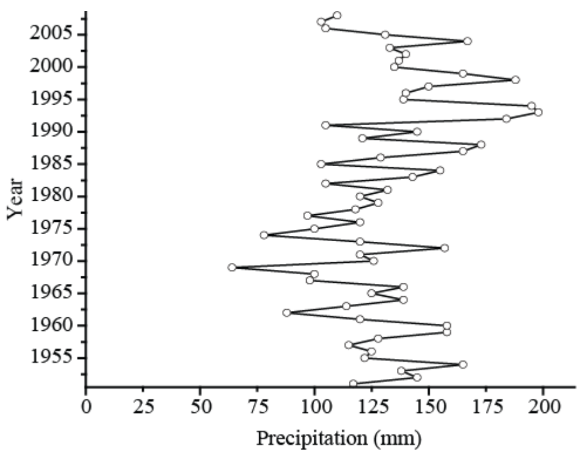

Fig. 3. Annual series change of the precipitation in study area.

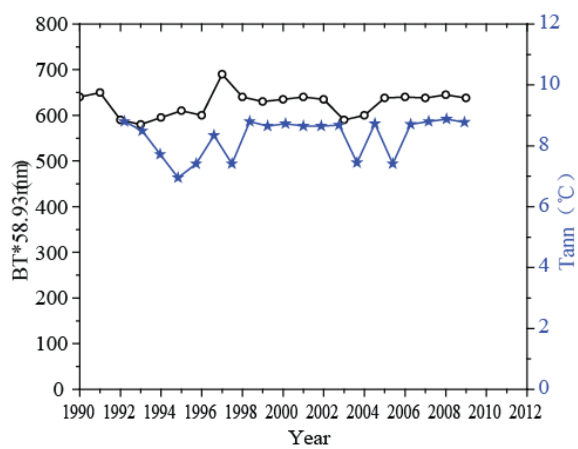

Fig. 4. Annual series change of Tann and BT*58.93 in study area.

It is shown in Table 3 that the mortality of *H. ammodendron* seedling has no linear correlation (R^2 = 0.05418, P = 0.1722) with underground water level, but has a significant positive correlation (R^2 = 0.57408, p<0.001) with soil conductivity, i.e., the higher the conductivity of 0-40 cm soil is, the more unfavorable it is for the survival of seedlings. The salt concentrated on the soil surface serves as a limiting factor in the survival of *H. ammodendron* seedlings while restricting the regeneration of *H. ammodendron*.

Discussion

Junggar Basin has a typical topographical feature of northern arid areas, which is made up of mountains-oases-basins. It is about ninety eight percent of the water resources that comes from rainfall in the mountains. Because of the small amount of rainfall in the plains, there are hardly any runoffs. Groundwater is mainly formed through the transformation of surface water. Natural groundwater recharge (infiltration of precipitation and mountain side lateral recharge) accounted for 14% of groundwater recharge, and river way seepage, canal seepage and field infiltration accounted for 86% (Deng, 2009). Since 2002, water-saving irrigation techniques have been promoted in a large area of the Manas river basin, which can save 50-60 % more water than the flood irrigation. Currently, because of the use of drip irrigation technology in 76-88 % cotton fields of the Eighth Agricultural Division of Xinjiang Production and Construction Corps along the Manas river as well as the construction of farmland seepage controlling channels, the amount of water transformed from oasis farm water into groundwater declined sharply. Meanwhile, the use of water-saving irrigation technology brings about a large scale reclamation. As there are not enough matching farmland canals, most of the irrigation water is extracted from groundwater, which may lead to a fall of groundwater level. This study found that there is a connection between the groundwater level and irrigation water of the upper reaches of the Junggar Basin. The highest groundwater level comes between March and April. With the increasing utilization of agricultural water since May, most of the well water level decline. The period from June to August is not only the peak of the upstream agricultural water utilization, but also a growing season of the natural vegetation. As a result, there is a large scale of groundwater exploitation in the upstream areas, causing the decline of groundwater level with the lowest level coming in July. Therefore, changes of agricultural irrigation methods in the upstream Junggar Basin result changes of groundwater recharge. The short interval between the peak of the upstream water utilization and the decline of groundwater level indicates that the excessive use of groundwater in the upstream basin has a direct impact on the decline of groundwater level.

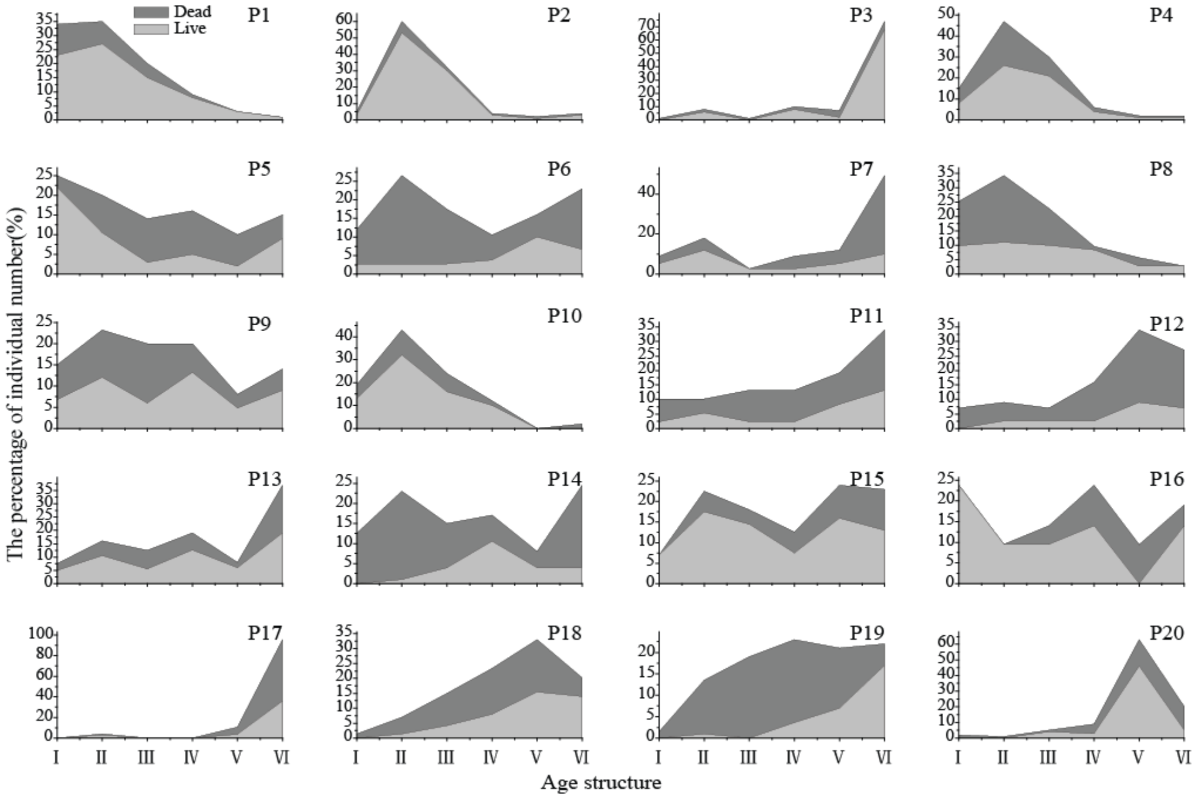

Fig. 5. The age structure distribution of *H. Ammodendron* population.

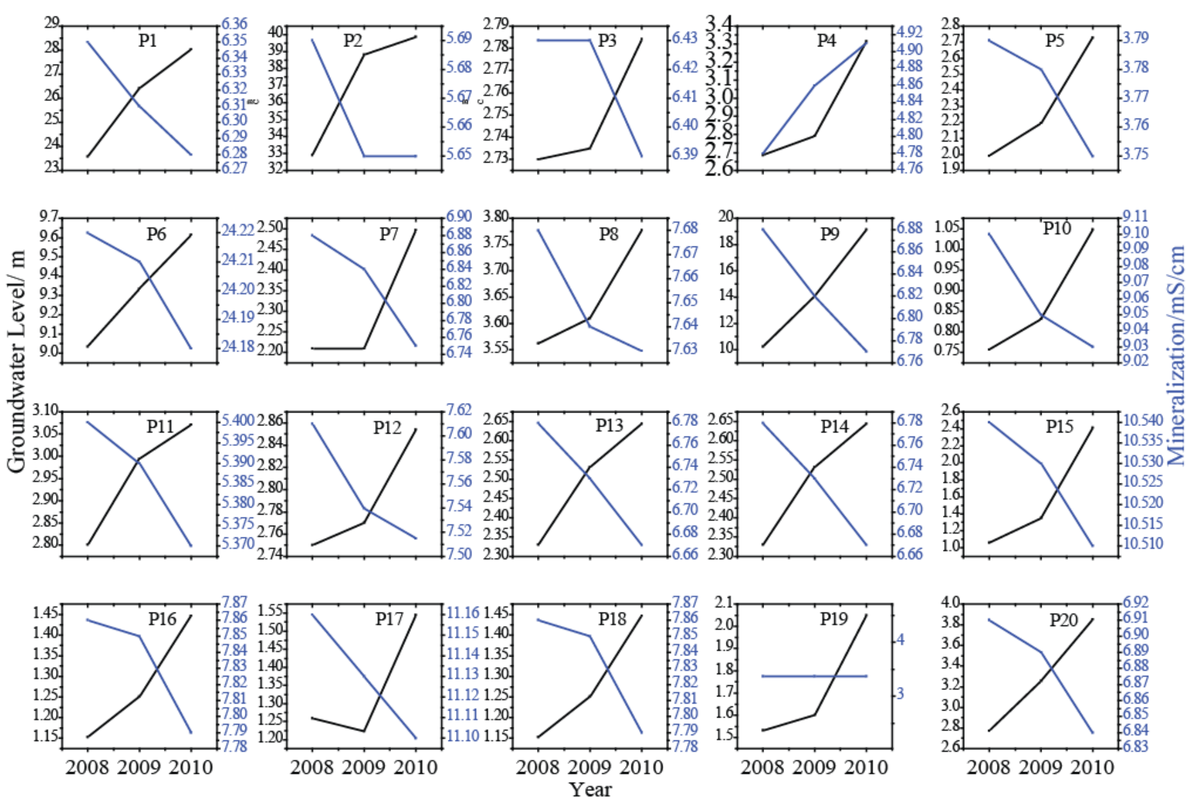

Fig. 6. Spatial and temporal variation of groundwater level and mineralization (Black line represents mineralization (that is groundwater quality) and blue line represents groundwater level).

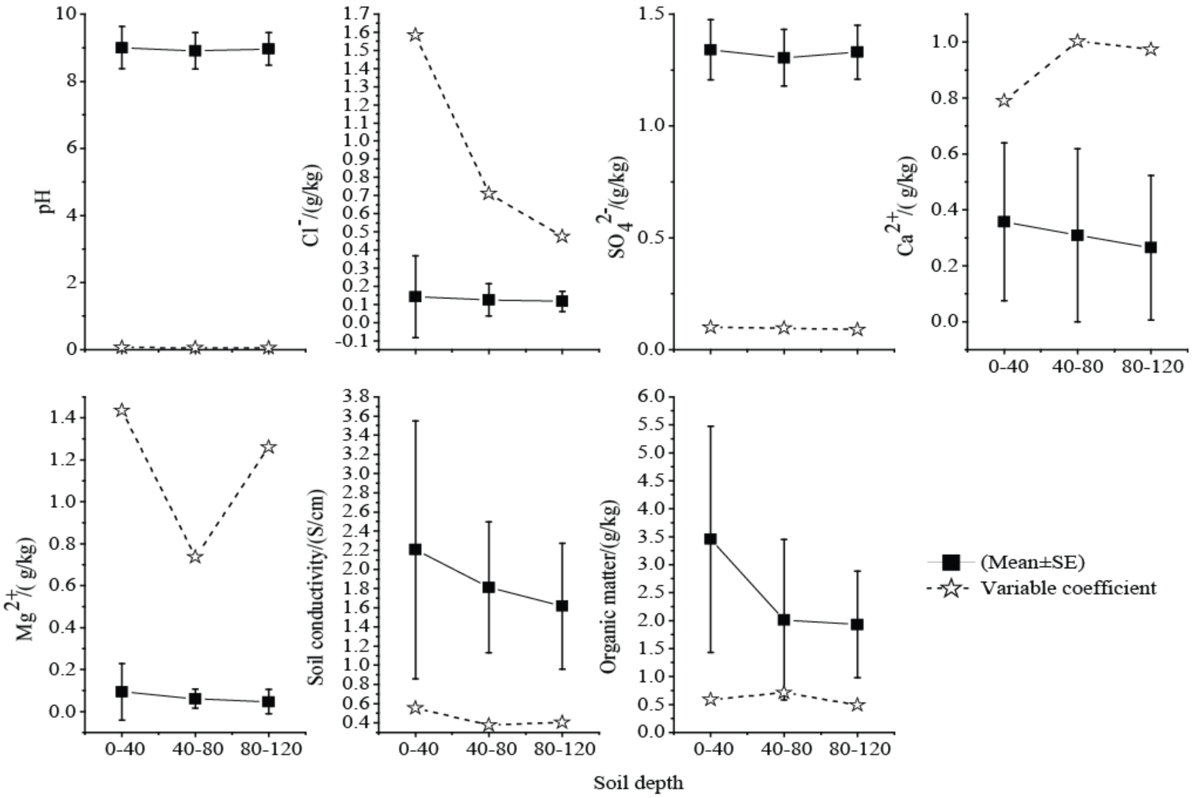

Fig. 7. Change of soil physical-chemical factors in different solum of sample plots (SE: Standard Error).

The increase in abandoned water from Manas river in 2010 has a certain effect on the rise of ground water level in the basin, although it goes up only by 4.3 cm on average. Based on the inter –annual variability of groundwater salinity, we found that groundwater salinity increased very significantly as a result of the infiltration of surface water and soil salt in 2010. We infered the formation of the Manas Salt Lake resulted from a long-term effect of the hydrodynamic ecosystem consisting of mountains, oases and basins. However, the current water-saving irrigation technology may lead to an accumulation of soil salt in oasis farmland, and it needs further study whether it will result in farmland salinization and other issues.

Study found that the species richness is not directly connected with the underground water level, but negatively correlated with soil conductivity, that is because the vegetation species in the study area are mostly herbaceous plants, over 70% of which are annual herbs. As they are shallow-rooted, it is hard to make use of groundwater while growing. 55% sample plots have salinized soil, as soil conductivity lies between 2mS/cm and 6 mS/cm, with an average of 2.206 mS/cm, and the pH value is above 9. Salt accumulation is prone to happen when underground water level is less than 5 m.When mineral elements accumulate on the soil surface, it makes it hard for water to infiltrate into the soil. As a result, there is a serious salt accumulation on the surface which sees a physical crust as the water in the depressions evaporates. Consequently, the plants are hit by salinity. Furthermore, it becomes difficult for the seeds to be kept on the surface. Since a lasting seed bank cannot be formed, settling of seed, germinating and seedling will be adversely affected. The vegetation species found in the sample plots are mostly salt-tolerant plants such as *Kalidium cuspidatum*, *Kochia odontoptera*, *Atriplex dimorphostegia* and *Zygophyllum fabago* as well as shrubs such as *H. ammodendron* and *Anabasis aphylla,* indicating a low level of species diversity.

A high soil salinity affects not only the distribution of annual plants, but also the regeneration of *H. ammodendron* population which is the constructive species. We found that groundwater level has no significant effect on the survival of *H. ammodendron* seedling. Howerver, there exists a significantly positive correlation between the mortality rate of *H. ammodendron* seedling and soil conductivity. 86% roots of *H. ammodendron* seedling are found in 0-60cm solum (Canadell *et al.*, 1996)while groundwater level is less than 3m. Consequently, there is a lack of groundwater to help the growth of *H. ammodendron* seedling, which, coupled with the high soil salinity, causes the physiological water shortage of *H. ammodendron* seedlings. The ability of plants to produce seeds, the ability of seeds to germinate and the ability of seedling to grow and survive jointly determine the regeneration ability of population. Hindrance to any of those abilities may lead to hindrance to the regeneration of the population (Soriano & Sala, 1984; Golluscio & Sala, 1993; Aguiar & Sala, 1998). The survey found although *H. ammodendron* plants in the degraded areas can produce a lot of seeds which can germinate under the condition that there is rainfall in the spring, seedlings are hit by a 90% mortality rate. As a result, the regeneration of *H. ammodendron* population is inhibited, leading to a scarcity of saplings in degraded areas as well as an aging structure and recessionary state of the population.

We found that the growth of *H. ammodendron* in the degraded plain area is affected by both groundwater level and water quality. Its coverage and decline rates have a quadratic function relation respectively with groundwater and have a linear correlation with the soil surface conductivity. *H. ammodendron* does not grow well and even die when the groundwater level is 3-4 m and the average conductivity of the soil surface is 3.43mS/cm**.** When the groundwater level is above 8m and the soil surface conductivity is only 1.24ms/cm, *H. ammodendron* is still in recession. *H. ammodendron* grows well when the conductivity of the soil surface is less than 4 g / L and the groundwater level is 6-8 m. As the samples collected in this research are based on different degradation level of *H. ammodendron* population and thus represent different recession stages, we can infer that the degradation of local *H. ammodendron* population is mainly a result of the gradual decline of groundwater level, water quality and surface soil salinization. We hold that the decline of groundwater level, water quality and surface soil salinization are the dominant factors in the vegetation degradation of this region.

The drying up of Manas river in the 1970s is an important historical event in Manas basin in northern Xinjiang. Its ecological effect was limited at that time except for the wetland plants. *H. ammodendron* population, which was far from the river, was hardly affected, as its average coverage in the study area can reach 25% in the early 1980s and the coverage in some specific areas can reach 50% (Hu, 1984; Zhong, 1990). However, the coverage of *H. ammodendron* drops to only 10.41% since 2008 with its decline rate reaching up to 40%. Changes of *H. ammodendron* population over the past 30 years is shocking. So we see although the vegetation degradation caused by the drying up of Manas river develops slowly, the impact on the ecological environment is profound. Currently, water-saving irrigation techniques are being promoted in the upstream basin, which leads to a large-scale disorderly land reclamation. Excessive exploitation of groundwater has significantly changed the hydrological cycle mode of mountains, oases and basins and salt-water balance mode (Deng, 2009). Salinization becomes worse as soil salt accumulates in the oasis region leading to, while the decline of groundwater level in the basin leads to vegetation degradation. Since the whole mountain-basin system of basin, oasis, mountain is involved in this process, the following serial ecological effects may be regional (Schwinning & Sala, 2004; Wang *et al.*, 2005; Maitre *et al.*, 2007; Fu *et al.*, 2009). So, it is an urgent issue as to how to coordinate the contradiction between economic development and ecological protection in the region and how to achieve a harmonious development of society, economy and nature.

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