DYNAMIC GEOECOLOGY: AEROSPACE MONITORING, MAPPING, FORECASTING

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ABSTRACT: The present review is concerned with new russian researches on remote sensing of the long-term dynamics of simple and complex ecosystems (i.e. base geoecological units) on local and regional levels. It develops new technology for data analysis based on comparison of multi-year aerial and space images and change detection. Using Markovian approach space-time distributed dynamic mathematical models are formed. This approach permits to deduce normative forecasting for the near feature and to optimize the restoration of ecosystems. This technology was executed for dynamic mapping and dynamic ecogeoinformation system. These approaches was tested in the study areas of deforestation of Middle Latwian Slope and Kostromskaya district, land degradation of Sal Steppe, severe desertification of Amudarya Delta and N.W. Caspian Sea Environs.

1. INTRODUCTION

Comparison of aerospace images from multiple repetitions, the measurements of the ecosystem area dynamics and the mathematical descriptions of area changes of the investigated ecosystems in the form of calculated equations of trends for 8-16 years, allow of some extrapolation for forecasting. As the most trends are nonlinear and multiple surveys are needed to be repeated no less then three times. The fequency and time interval depends on rate in area changes. As a rule, in stable ecosystems a representative time interval lies roughly 8-10 years, in moderate dynamic - 5-7 years, in middle dynamic 3-4 years, in high dynamic - 1-2 years, in disastrous dynamics - every year (Vinogradov, 1988a).

2. MONITORING OF THE SIMPLE ECOSYSTEM DYNAMICS

Comparison of multi-year aerial and space photographs is used for calculation of area changes in particular ecosystem sites, which are recognized on imageries with high accuracy (probability of correct recognition is over 0.95). Such are drift bare sands, eroded soils, forest cuttings, forest burns, urban fringes, arable fields, lakes and swamps, etc. These long-term changes are drawn by the ecological trend lines. A trend, by definition, is such ecosystem change, in which the ecosystem state is not repeating in any time scale, and the direction of drift continious both at short time intervals (days, monthes) and at long ones (years, decades). Tacking into account aerospace surveys streching from the late 1940th the early 1950th, we could compile long-term ecological trends for the duration of 30-40 years. The definition of a trend requires a statistical analysis. Thus, an ecological trend describes all the multi-temporal variations of ecological features with a expected accuracy (0.8 and more) and high probability (0.95 and more) and a sufficient data evaluation tested by different criteria (Student's, Fisher's, Kolmogorov-Smirnov's, etc.).

Using sequential aerial and space surveys the long-term trends of area changes of separate ecological sites were presented for objective description of arable fields area changes in true steppes in the Rostov-Don district, Russia, during 1962-1978 (Vinogradov et al., 1980(1979)), the desertification of the Lower Amudarya Delta due to waters and soils having dried up, Karakalpakia, during 1962-1978 (Vinogradov, 1984, Vinogradov, Frolov, Popov, 1989), the land degradation of the Precaspian Black Lands due to expansion of mobile sands in semideserts, Kalmykia, during 1954-1984 (Vinogradov et al., 1986(1985), Vinogradov, Kulik, 1987).

2.1. BLACK LAND STUDY AREA

The most complete aerospace experiment of this kind was carried out in the Black Lands [Tschernye Zemli] of Kalmykia (Vinogradov, Lebedev, Kulik, 1986(1985), Vinogradov, Kulik, 1987). Firstly the set of sequential surveys of 1954, 1958, 1961, 1970, 1976, 1979-1981, and 1984 was used to describe the non-linearity of the desertification trend.

There, on sandy soils, previously covered with thick and high tallgrasssagebrush vegetation, an extensive desertification area have developed as a result of heavy overgrazing in the last decades. These areas represent mobile sands and deflation scarps deprived of vegetation cover. They are clearly recognized by light spots on the panchromatic aerial and space photographs. The multitemporal aerial and space imageries of this region were obtained in different years between 1954 and 1984. It is clear from aerial photographs of 1953, 1954, 1958 that in the Black Lands the light spots of mobile sands on the dark-grey background of fixed sands had no large dimensions and occupied about 3%. On aerial and space photographs of 1976, 1979, 1981, 1983 and 1985 the fast growth of deserification in the study areas can be seen. Many new light spots of mobile sands devoid of plants occured with a total area of some hundreds of hectares. As it demonstrated by comparison of the repeated images, the relative area of the cores of desertification in ecoregion increased by

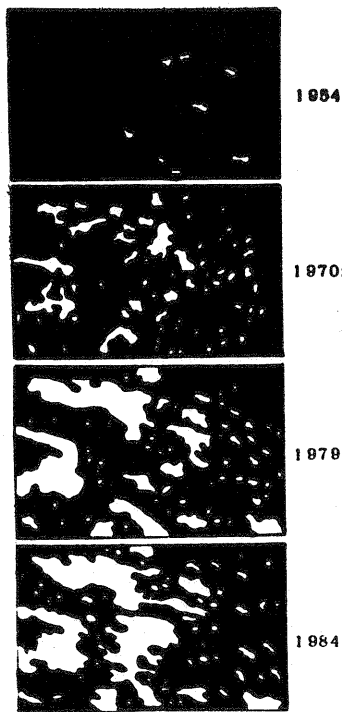15 times by 1985, reaching by 1976 15%, by 1979 22%, and by 1983 33%.

Fig.1 Displays of change detection of relative area of drift sands devoid of vegetation (white patches) within the vegetated areas (dark background) in the Black Lands Test Area as derived from sequential aerial photographs.

The sequential ground observations, aerial photographs (1954-1984), and space surveys (1975 -1984) in the course of 30 years were used for the mathematical expression of the tendency of the area dynamics of mobile sands. The growth of the desertification area, as indicated by the enlargement of the area of mobile sands, can be described by an exponential function:

$$Y = a \exp(k (X_i - X_o)) \quad [1],$$

where Y is a relative area of mobile sands, as was seen in aerial photographs, for the current year X_i, a is an area of mobile sands at the year before onset of the process, when the ecosystems were in a stable state X_o, that is assumed in 1954, k is a power, showing the accelerated increase in the area of mobile sands. For the study area this function [1] is expressed by equation (Fig.2):

$$Y = 3.064 \exp (0.086(X_i - 1954))[2].$$

Retrospective analysis of desertification trend using the first derivative in the equation [2] permits dividing it into three dynamic stages. It follows from a retrospective analysis of the equation [2] that in 1954-1958 the ecosystems of the Black Lands were in a
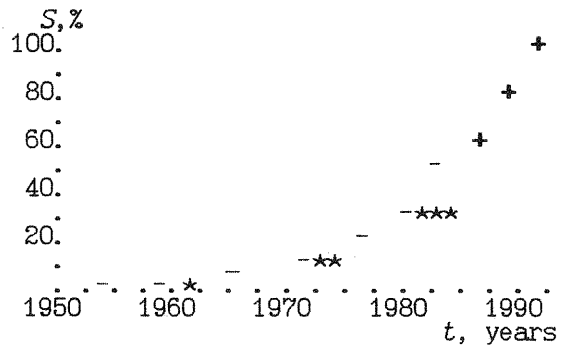

Fig.2 A disastrous trend of relative area (S, %) expansion of drift sands in the Black Lands Test Area in Kalmykia due to desertification during 1954-1984 as revealed from sequential aerial and space photographs with admissible (∗ the beginning of 1960s), limit admissible (∗∗ the beginning of 1970s) and disastrous (∗∗∗ the beginning of 1980s) levels of disturbance , where -- observed state, ++ predicted state.

stable condition. Mobile sands and deflation scarps occupied a negligible area of less than 3-5%. Toward the end of the 1950s and the beginning of the 1960s the ecosystem's state was stable, the area of drift sands did not exceeded 5% of the whole area, and increase of its area was less than 0.5% per annum. An acceleration process of desertification began in about 1960, when the area of wind-eroded sands exceeded 5%.

Then, by the end of 1960s and the beginning of 1970s the area of open mobile sands was increased to 10 -15% of the whole area, with annual increment in the order 1-1.5% per annum. By near the beginning of 1970s the pressure on the rangelands and area of open sands had reached the maximally permissible level, whereupon the ecosystem successions became hardly reversible.

Finally, in the end of the 1970s and the beginning of the 1980s the area of mobile sands and open deflation scarps devoid of vegetation exceeded 40-45% of the whole area, with annual increment 3-4%, i.e. 40 000 ha per annum. In 1979 -1984 desertification process had reached a disastrous dimension and became virtually irreversible.

2.2. AMUDARYA DELTA STUDY AREA

By comparing the results of multiple aerospace surveys, the ecological trends of changing elementary areas of the most ecosystems were also non-linear. In study the area of the Lower Amudarya delta, Karakalpakia, which over the last tens years has experienced heavy desertification. From investigating the area dynamics of ecological sites of the Lower Amudarya delta, utilizing multiple aerospace images at 8-years intervals for 1962, 1970, and 1978, the non-linearity of ecological trend is evident. The non-linear trend is a curve of the form:

$$Y = a/+/b(X_i-X_o)^p/+/c(X_i-X_o)^q \quad [3],$$

where Y is an area of delta occupied by investigated ecological site, Xo is a conventional year of the beginning of the process of decrease of site area , Xi is a current year of aerospace survey, a, b, c, p, q are parameters of the equation.

The area dynamics trend, exemplified by the ecological lake and swamp sites of the Lower Amudarya delta, is described as a descending curve with acceleration of the area decrease:

$$Y = 13.70(1978 - Xi)^{1.06} - 8.24(1978 - Xi)^{1.19} - 0.02 \ [4].$$

The ecological trend calculated from the above equation [3], which was derived from aerospace images 1962, 1970, and 1978, showed, that a steady state of the lake and swamp areas with an overgrown of riverside water plants existed in 1954, when these facies occupied about 32 % of the Lower Amudarya Delta Test Area. By the same equation [4], since 1978 the lakes and swamps of former river have almost completely disappeared. The trend of the area dynamics for separate ecological sites is described by a curve ascending with an decreasing rate of area increase with time.

The trend of the area increase at a salt meadow site with saline soils overgrown by salt-tolerant plants, such as *Tamarix hispida* and *Aeluropus litoralis*, is also described by a non-linear equation. The numerical expression of the ecological trend of the area change (Y) of this site has following form:

$$Y = 6.56(Xi - 1961)^{0.50} - 2.22(Xi - 1961)^{0.24} - 0.05 \ [5],$$

where Xi is an year of current aerospace survey. In solving the equation [4], the year when the site change began was not long before 1962, and is conventionally assumed to be 1961. Thereafter, the site area started to increase rapidly, but after 1982, according to the calculated trend equation [5], its area became stable, and subsequently after occupying 24% of the total area of the test region, the increase of this site area has practically stopped. Using this procedure the trends of area changes over the rest ecological sites of the study area could be calculated and expressed in numerical form by analogous power equations.

3. ANALYSIS OF SYSTEM'S DYNAMICS

The best approach to prediction of ecological changes is space-distributed dynamic modeling of the large ecosystems (Vinogradov, 1980, Larson, 1982, Heusden, 1983, Lo, Shipmen, 1990). The most comprehensive study case is the long-term aerospace monitoring of subdesert sand hills region of the Black Lands Test Area in Kalmykia within the North-Western Precaspian Environ. Comparison and analysis of six successive aerospace surveys during 1954-1984 permitted to describe the long-term dynamic trends of complex ecosystems in quantitative terms (Vinogradov, Tcherkashin, 1990, Vinogradov, Frolov, 1991).

Despite this detailed and correct description of the long-term area changes for the ecosystems in the Black Lands we do not know the critical disastrous time of profound and irreversible transformations of regional ecosystem set. This transformation may lead to disastrous ecological consequences in the future. Also, it is necessary to determine the economic developments associated with these disastrous changes over time.

For describing of this critical disaster time we used an approximation of the ecosystem dynamics in terms of Markovian chains theory. Firstly, transition matrices of one ecosystem to others were calculated, using data provided with multi-year aerial and space surveys. Subsequently, the stationary distribution of areas of the ecosystem classes were calculated for each transition matrice in strict sequence:

$$S* = [S*(1), \quad S*(2), \quad S*(3), \quad S*(4)] \ [6].$$

The stationary distribution determines the final ecosystems state, i.e. in the stable state, where common areas of ecosystem classes do not change with time although transitions between sites are possible. Any Markovian chain has a stationary distribution of transition probabilities and stable probabilities in each state (in our case, the probability of each site in the i-th state correspond to area $S*(i)$ of i-th ecosystem). Stationary distribution of ecosystem areas $S*(i)$ meets the following constraints:

$$S*(n) = S*(n) \times M(n) \ [7],$$

where $M(n)$ is a matrix of transition probabilities during time interval n.

For evaluation of the state of an ecoregion and for study of transformation processes, which stand for transition from one stable state (from subclimax before 1954) to another (to disclimax of bad lands after 1992) was used a regional non-stability coefficient E:

$$E = \frac{\sum [S*(i) - S(i)]}{2} \ [8],$$

where $S(i)$ is an area of i-th ecosystem classe as derived from aerial and space surveys, $S*(i)$ is an area of i-th ecosystem classe as revealed from stationary distribution. A non-stability coefficient (E) points to the relative area (in %) of the study region, which should be changed to reach the quasi-stable state. This corresponds to a matrix of transition probabilities during a given study time-interval. A dynamic surface of E as an expression of maximum reduction in area was found for time-interval between surveys of 1970 and 1979-1981. Apparently, this maximum E is related to the middle of the decade, roughly 1974. This critical year is a turning-point when the changes in the ecoregion became irreversible and a bifurcation was developping. After this

growth of non-stability is complete, succession lead to second stable state, where the greatest area of the ecoregion will occupied with drift sands and bad lands.

The ecosystem succession is influenced by desertification, and the coefficient E was calculated to describe the excessive growth of livestock population. The main cause of the ecosystem dynamics over the Black Lands is overgrazing of excessive livestock, which has increased during the last 30 years from 1 million to 4 million and over. As a result, there was an inreasingly high impact on exhausted pastures. The most important depression of livestock population by 0.3 million was observed during next 2 years. Then, the livestock population incresed in next few years alternating with small depressions of population (by 3-6%). By examining the dynamics of livestock populations and the area change relationship of ecosystem classes the conditional impact on the pasture ecosystems $B(t)$ was calculated:

$$B(t) = \frac{\overline{S}(t) \times \overline{F}(t)}{C(t)} \quad [9],$$

where $\overline{S}(t)$ is a vector-row of area of the ecosystem classes, $F(t)$ is a weight coefficient of production capacity of the ecosystem classes, $C(t)$ is a livestock population, t is time. The phase space of the ecosystem dynamics during 1954-1984 is drawn in the phase coordinates E, B, and t (fig. 3).

Analysing the phase space we were able to reveal the time of structural reconstruction over the study region, viz. 1974. Subsequently, on the basis of these data a curve $B*(t,E)$ was plotted. It describes the limited admissible impact on the ecosystems depending on location of this curve in the phase space of the ecosystem dynamics. Retracing all possible tracks of the regional dynamics in the studied phase space we selected the tracks that led to disaster consequences. Conversely, if the impact on the pastures remained stable, roughly at the level developed in the 1960th, the track of the regional dynamics did not intersect the curve of the maximal impacts $B*(t,E)$. In this case the disaster transformation of ecosystems would not have happened although coefficient E had reached high values. The restoration of degraded ecosystems in the last case would be easier to work with now. Hovewer, if increased impact on pasture ecosystems over the Black Lands had reached a turning-point earlier, then the relationship among phase coordinates could be plotted on curve of maximal impact $B*(t,E)$.

The above described quantitative analysis of the long-term dynamics gives grounds to conclude that the sharp rise of livestock population during 1972-1974 was the turning-point of trend of the disastrous dynamics over the Black Lands. Thus, excessive growth of livestock population in the region without considering rangeland carrying capacity
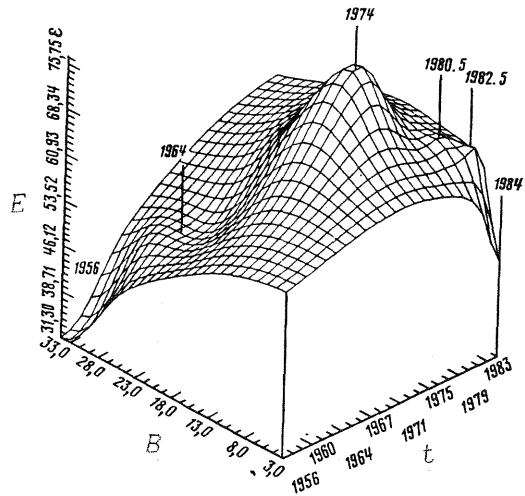

Fig. 3. The phase space of the pasture ecosystem dynamics over the Black Lands with coordinates: E is a non-stability coefficient, B is a livestock impact on ecosystems (thousands of heads), t is time (years). Maximum of E falls on time (1974) of turning-point of the ecosystem dynamics with forecast of ecological disaster of 1985-1990 before 10-15 years.

predetrmined the destructive concequences of the present-day rangeland degradation within one of the most ancient of livestock region as earlier as 1975. Following more moderate and rational land use policies it would be possible to avoid these disastrous consequences. Finallly, analogous procedure could be used for prediction of turning-points in time of critical stresses on ecosystems under human impact over vaste regions.

4. DynEGIS

In this relation we proposed a Dynamic EcoGeographical Information System [DynEGIS], which is intended for registration and analysis of dynamic ecological phenomena. DynEGIS is the most reliable form of GIS for monitoring disaster regions. In DynEGIS transformation of input data in the format of spatial ecological units highly increases information capacity and data compactness. As result, a volume of DynEGIS is decreased and information capacity is increased. In this case, each combination of the range of ecological feature correspond to one information cell in DynEGIS (Fig. 4).

The choice of adequate mathematical model of the ecosystem dynamics has the greatest importance for data handling and data analysis in DynEGIS. Use of adequate models in DynEGIS increases the range, reliability, and accuracy of operations and especially forecasting. The mathematical model of the ecosystem dynamics involved in DynEGIS registers the whole number of succession stages, provides the optimal strategy of land resource management, evaluates the levels of admissible impact on natural ecosystems, and reveals the stability conception.
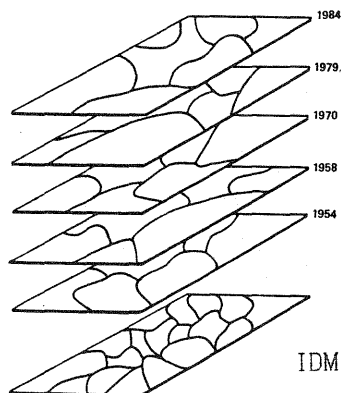
Fig. 4 Milti-temporal integration of aero-space images of the Black Lands Test Area in the integral dynamic map (IDM) within the frame of DynEGIS.

The Markovian approach meets the demands of mathematical modeling of the ecosystem dynamics and is tested over some regions where the complex ecosystem dynamics was studied using sequential aerial and(or) space images.

The choice of Markovian model depends on the quantity and quality of input information, and on the accuracy and resolution requirements for cartographic displays derived from sequential images. At the first stage of DynEGIS formation, where two time sets of images were involved only, we used homogeneous simple Markovian chaines (Vinogradov, Popov,(1988)1989). Taking into account the simple model and allowing the constant transition probabilities it is possible to forecast the ecosystem state no more then 1-2 studied time periods onwards. As a rule, the accuracy of forecasting on the basis of this simple model is acceptable with relative error of 10% of changed area for the first 5 years. But simple model could not used for long-term forecasting, since the accuracy of forecast rapidly drops with increase the number of steps of prognostic intervals more then two.

An essential improvement of the Markovian approach is accomplished when we would involv in DynEGIS aerial and(or) space data more then two times of surveys. These multi-temporal data permit forming the mathematical models of the ecosystem dynamics on the background of inhomogeneous Markovian chains, which take into account the time oriented changes of probabilities of transition. Such models are described as follows:

$S(i) \times M(i) = S(i+1)$, $S(i+1) \times M(i+1) = S(i+2)$ etc., $F \{ M(i) \} = M(i+1)$ [10],

where: $S(i)$ is a vector-row of area change of each ecosystem element at i-th time-point, $M(i)$ is a matrix of probabilities of transition at i-th time-interval, $F \{.\}$ is an operator describing the changes in the probabilities of transitions at different time-intervals.

As an example of this model involved in DynEGIS we used an approximation of long-term dynamics of ecosystem classes over the Amudarya delta as derived from comparison of space surveys of 1970, 1975, 1980, and 1985 (Vinogradov, Frolov, Popov, (1989) 1990).

With increase of sequential survey sets more then 3 it is obvious that the transitions between ecosystem classes are not random, but are determined site-by-site. During this procedure each initial site is divided into some parts with transition from set to set by 2-3 and more parts. There each final and current state of each ecosystem classes depends on previous states and succession traces. It is obvious that common Markovian approach is insufficient since it do not involves relations between past and future state.

Thus, an adequate discription of the long-term dynamics of vaste ecoregion is possible with comlex Markovian chains using 4 and more survey times. This long-term succession determines the transition probabilities during representatively long time-interval. Practically, this procedure based on application of inhomogeneous Markovian chaines, involves the maps of transitions between all classes (the maps of the dynamic units) beside of the conventional maps of land units. In output from this model we receive the true dynamic maps. We could use different approaches to complex Markovian chaines. The common feature of these approaches is next procedure: the transition probabilities on each step depend on previous state and successions.

For execution of this Markovian model in DynEGIS it is necessary to determine some additive conditions. At first, the test area should be representative and sufficiently large, no less then 10 000-100 000 ha to allow for all sites, even small, all transitions, even rare, between all ecosystem classes. When we have insufficient large test area the many transitions, especially uncommon, are delated. In this case we could not form closed Markovian model. When we have surplus large study area with appreciable genetically heterogeneous landscapes the Markovian chaines reduced to loosely connected and isolated subsystems, and model does not work either.

5. CARTOGRAPHY OF THE DYNAMICS

In output from DynEGIS we propose cartographic data representation. The most universal would be output in cartographic representatation of the ecosysten dynamics with delineation of transition traces and indication of rate between each sites by itself. But, visualization of these multi-temporal data involves great difficulties.

We have succeeded in taking output cartographic displays of the ecosystem dynamics using composition of two survey sets. The main advantage of these output cartographic displays is a matrix explanatory legend with indication of transition probabilities for all ecosystem classes in each cell for the

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time interval between these two survey sets. To our regret, these matrix explanatory legends are too bulky, and reflect the linear changes only. For example, over the Amudarya delta test area we revealed between the two space surveys in 1975 and 1980 23 transition traces only. When we used an inhomogeneous Markovian model with 3 survey sets number of possible dynamic traces reached 58.

Visualization of the output dynamic cartographic data from multi-temporal sets is based on the representation procedure of differents transition traces in the space of states integrating by common features of transition branches. For example, the output cartographic display reveals all transition traces from one intial true meadow ecosystem class during 1970, 1975, 1980, and 1985 data sets. This display reveals 6 transition traces from 1970-th initial ecosystem class with all transitions into other ecosystem classes due to desertification (Fig.5):
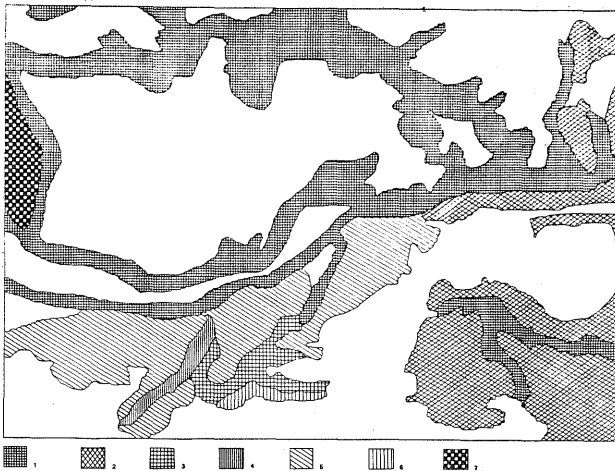

Fig.5. Cartographic display output from DynEGIS, where are visualized changed ecological classes of the Lower Amudarya Delta Test Area during 1970 (first value), 1975 (second value), 1980 (third value) and 1985 (fourth value) with traces: 1- 4-->4-->4-->4, 2 - 4-->4-->4-->5, 3- 4-->5-->6-->6, 4- 4 --> 7-->7-->7, 5- 4-->4-->7-->7, 6- 4--> 4--> 4-->7, 7- 4-->5-->5-->10, where 4- true meadows/tugais, 5- saline meadows, 6- salines, 7- dry meadows, 10 - irrigation fields.

Above all, we had the "zero" trace (1 - 4-->4-->4-->4), where probability of transition of self-to-self during 15 years reached 40.2%. The first trace involved the transition of meadow class from 1970 to meadow-saline class in 1985 (2- 4-->4-->4-->5) with the most important probability of 30.4%. The second wide-spread trace consisted in transition to meadow-saline class in 1975 and to saline in 1980 (3- 4-->5-->6-->6) with probability of 20.0%. The remaining traces were less important. The fourth transition trace to meadow-desert classe

in 1975 (4- 4-->7- ->7-->7) had the low probability of 1.3 %, and the fifth - to the same class in 1980 (5- 4-->4-->7-->7) - 0.8%. The sixth transition trace to saline class in 1985 (6- 4-->4-->4-->7) had the probability of 2.7 %. The seventh transition trace to meadow-saline class in 1975 and then to irrigation field class in 1985 (7- 4-->5--> 5-->10) had the probability of 2.3%.

Analogous visualized cartographic output was accomplished with DynEGIS for all 9 rest initial ecological classes of the test area with quantitative values of probabilities of all transition traces. Over them, DynEGIS could get output for the reverse dynamic purpose, for example, to depict visualized cartographic display which reveals different transition traces resulting in-one final ecosystem classe.
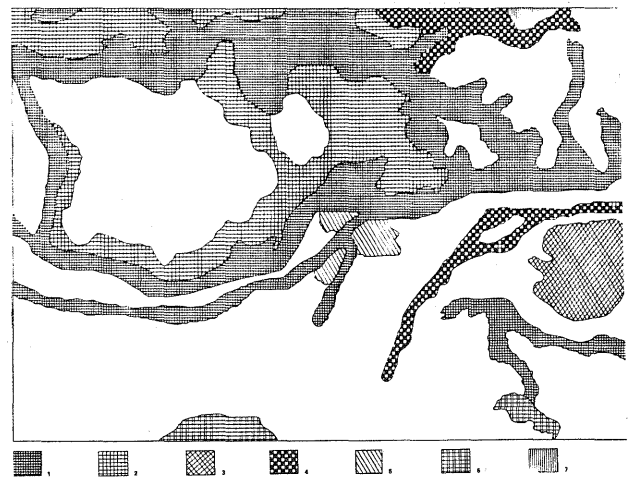

Fig.6 Cartographic display output from DynEGIS, where are visualized unchanged areas of ecological classes during 1970, 1975, 1980 and 1985 space surveys of the Lower Amudarya Delta Test Area: 1-true meadows/tugais, 2-saline meadows, 3-deserts, 4-dry meadows, 5-irrigation fields, 6-swamps/water bodies, 7-saline deserts.

Besides the output of changed sites it takes an high interest in the output cartographic display with outgoing of alone stable ecosystem sites. The area and structure of the stable ecosystem sites did not change during the time of DynEGIS functioning and during of the data base creation. For example, the output cartographic display of stable sites of all ecosystem classes is depicted within the same test area over the Amudarya delta (fig.6).

The whole area of stable ecosystem sites ocuppies 42% of Test Area, where the area of stable true meadows/tugais being 22%, saline meadows - 10.5%, dry meadows - 3.8%, deserts - 2.75%, irrigation fields - 1.3%, swamps/water bodies - 1.2%, saline desrets - 0.2%.

Thus, visualized cartographic output data from DynEGIS are very diverse. As the object of DynEGIS is more specified and as the purpose of DynEGIS is more narrow the functioning of DynEGIS is more successful.

6. LONG-TERM FORECASTING OF THE ECOSYSTEM DYNAMICS

6.1 Extrapolation Forecasting in the Black Lands Test Area.

The knowledge of current tendency of the dynamics of drift sand area (see Eq. 2, Fig. 2) makes it possible to resort to an ecological forecasting. It is assumed that having determined the current tendency it could be extrapolated on the future by at least one third of the investigated time interval, i.e. in our experiment by 10 years forward to 1994. According to Eq. 2 and considering a representative time interval 1954-1984, we find that bare drift sands devoid of soil and vegetation would occupy 56% of Test Area by 1986, 84% - by 1990, and 100 % - by 1992.

6.2 Complex Forecasting in the Amudarya Delta Study Area

Mathematical modeling of the dynamics of the composite ecosystems is more complicated but forecasting on the basis of complex analysis is more correct. Previously we used simple Markovian chains for ecological forecasting. These simple Markovian chains were compiled from comparison of two sets of aerospace surveys only. According to this procedure the simple transition matrix for all ecosystem classes during the training time interval M(1-2) was multiplied by the transposed vector of final state V(2) of each ecosystem classe within the study area. As the result we received a prognosed vector of forecasted state on one time interval forward V(3):

$$M(1-2) \times V(2) = V(3) \quad [11].$$

In our study area of the Lower Amudarya delta the transition matrix M(1980-1985) served as a training sequence of the ecosystem area dynmamics for ecological forecasting on 5 years forward. Subsequently, M(1980-1985) was multiplied by the vector of final state V(1985) and we received the prognosed vector on 1990, i.e. V(1990). After this, obtained M(1985-1990) could be multiplied by V(1990) for receiving V(1995) (i.e. forecast for 1995), then likewise for 2000, etc. (Vinogradov, Popov, 1988).

At present time taking into account the non-linearity of the dynamic trends we prefer to use an inhomogeneous transition matrices. These inhomogeneous transition matrices request more then two survey times for the same study area. For compilation of these inhomogeneous transition matrices we used photo-interpretation maps of three survey times 1975, 1980, and 1985 which had been received from spacecraft "Salyut-4, 6, and 7".

A normative forecast of the ecosystem dynamics to 2010 reveals the follow area changes of all ecosystem classes (Fig. 7).

The use the inhomogeneous Markovian model in DynEGIS depicts the forecast of area changes of each ecosystem classe to
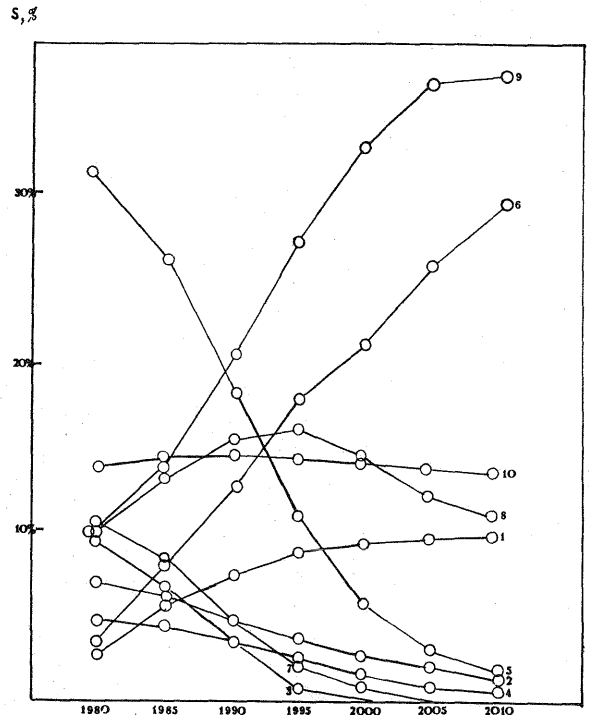

Fig. 7 Predicted trends of area changes of ecosystem classes for 1985-2010 based on training sequence of area change data of 1975, 1980, and 1985 space surveys, where ecosystem classes: 1- saline swamps, 2- swamps/water bodies, 3- wet meadows, 4- meadows/tugais, 5- saline meadows, 6- true salines, 7- dry meadows, 8- saline deserts, 9- true deserts, 10- irrigation fields.

2010 (fig. 7). The most rapid growth is predicted for desert ecosystems by 2.5 times and saline ones by 3 times in comparison with 1985. Only these two arid ecosystems could occupy to 2010 nearly 70 % of the whole area of the Lower Amudarya delta. Conversely, the area of dry meadow ecosystem class would be decreased by 9 times, wet meadows by 30 times, and the whole area of mesomorphic ecosystem classes will be dropped to 5% of the delta. Some ecosystem classes would be disappear in the near future (for example, wet meadows to 2000, true meadows/tugai forests and shrubs to 2005). But two ecosystem classes will not change their area sufficiently. Area of irrigated fields will be supported on level of near 13-14% by man's efforts. Subsequently, the predicted trend of area of intermediate saline deseret ecosystem classe would have a stable fluctuated form on the subclimax level.

6.3. Testing the Forecast in the Lower Amudarya Delta Study Area.

An experimental control of forecast is accomplished by the epignosis method. According to this procedure the previous studied time interval was used as a

training sequence of the ecosystem dynamics for the forecast of the ecosystem state on the recent time, which could be tested during the field control studies. In our study area the transition matrix $M(1975-1980)$ was used as training sequence for prediction on 1985. Then, predicted areas of all ecosysytem classes $V(1985)$ were controled during the ground truth in 1985 (Tabl.1).

Tabl.1 Comparison of predicted area data based on training time interval between 1975 and 1980 space surveys for 1985 and field controled data in 1985 (in %%).

Ecosystem classes	Predicted area	Controled area	Error area
Saline swamps	2.50	4.84	2.34
Swamps/waters	6.93	5.69	-1.24
Wet meadows	8.18	5.77	-2.41
Meadows/tugais	4.33	4.18	-0.15
Saline meadows	29.96	25.08	-4.88
True salines	4.35	7.51	3.16
Dry meadows	9.48	7.51	-1.97
Saline deserts	10.76	12.48	1.72
True deserts	10.00	13.25	3.25
Irrigation fields	13.51	13.69	0.18
	100.00	100.00	/10.65/

The comparison of predicted and controled areas in 1985 reveals the mean error of forecasting for 5 predicted years. The mean error of forecasting is 10.65% of the whole changed area for 5 predicted years. For more remote forecasting on future errors would be more serious. In this study case we estimated the mean error for 10 predicted years near 16%, for 15 near 25%, etc.

7. CONCLUSION

Above mentioned geoecological aero space studies of the long-term ecosystem dynamics were executed during the last decade within the frame of Scientific Ecological Programme of the USSR and Russian subprograms of some international programs - International Programme of UNESCO on "Man and Biosphere" and International Geosphere Biosphere Programme "Global Change".

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