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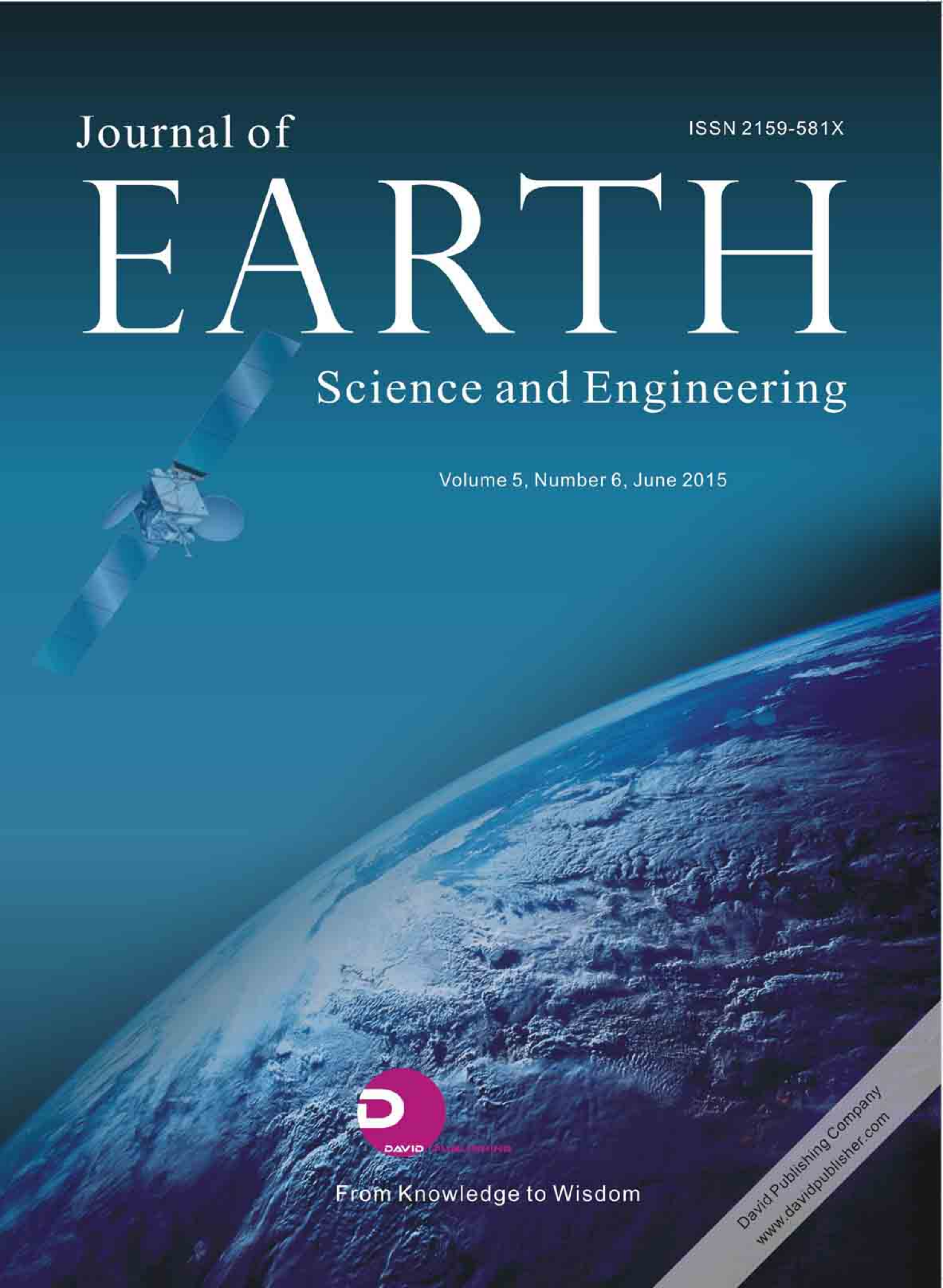

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Assessing the Impact of Year 2012 Drought on Corn Yield in the US Corn Belt Using Precipitation Data

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Abstract: Extreme weather and climate events are likely to cause disastrous consequences for agriculture and food security. This study investigated the impacts of drought in year 2012 on corn yield in the United States Corn Belt by integrating county-level crop yield data from the USDA NASS Quick Stats database and precipitation data from the NCDC GHCN-Daily database. It is found that precipitation over an 8-week period in corn growth stages is critical for corn yield, the logarithm of precipitation during the period explained 55% of corn yield variation. The results indicated the importance of water supply in corn silking stage, and provided an approach to assess the impacts of drought on corn yield quantitatively.

Key words: Corn, drought, yield, precipitation, Corn Belt.

1. Introduction

Climate change involves complex interactions and changing likelihoods of diverse impacts. As rapid population growth and climate change present far-reaching threats to food security, it has become vital to assess the impact of extreme weather events on agricultural productivity. Climate models predicted drastic changes in water availability and increase of land areas in drought in near future due to climate change [1]. Although localized effects may be difficult to predict, the overall severity and extent of drought is projected to increase. These extreme weather events are likely to cause major crop losses, which will have drastic political, economic, and humanitarian consequences [2, 3]. Assessing and responding to these crises require a deep and quantitative understanding of how drought impacts agricultural yield [4].

Currently, corn is the major food crop in much of sub-Saharan Africa, Southeast Asia, and Latin America, while in the United States it is the major cash crop for the Midwestern Corn Belt and is essential to the production of fuel and livestock [5]. While plant breeding and genetic engineering have been used to improve the drought-tolerance of corn, drought during critical development periods still has serious consequences [6]. This vulnerability was demonstrated as recently as 2012, when severe summer drought over much of the United States Midwest crippled corn yields and drove prices to record highs [7]. Many studies have been conducted to quantify the effect of drought on corn yields. By controlling watering regimes to simulate drought and comparing the characteristics of different corn hybrids, experiments have profiled the effect of water stress throughout corn growth and development. These studies indicate that adequate moisture is crucial during the silking stage, when water stress can delay development of silks (which receive pollen for fertilization) and prevent kernel formation [8-10]. Water stress after this stage, when plants direct resources towards kernel development, can also severely reduce yield [8, 9].

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Estimating corn yields using agricultural data also offers important insights. Existing methods include sophisticated models which account for factors including plant physiology, soil characteristics, and even economic factors [2, 11]. While these approaches give excellent results for small regions where parameters such as soil type, variety, or planting date are known, the large number of parameters limits their applicability when detailed data are not available. Other approaches have used climate data and historical yield to fit a model, but this has generally been limited to individual pilot fields, a few counties, or state-level average data [12-14].

This study addressed these issues by integrating historical precipitation data from the National Climatic Data Center's GHCN (Global Historical Climatology Network) -Daily database [15] and yield data from the NASS (National Agricultural Statistics Service) [16] at the county level in order to assess and quantify the impact of precipitation on corn yield over a large area of the United States Corn Belt.

2. Data and Method

2.1 Study Area

In the United States, corn is the major cash crop for the Corn Belt and is essential to the production of fuel and livestock. The Corn Belt includes Iowa, Illinois, Indiana, and parts of Michigan, Ohio, Nebraska, Minnesota and Missouri. In this study, five major corn-producing states in the US Corn Belt were chosen: Iowa, Illinois, Indiana, Ohio, and Minnesota, containing a total of 434 counties. Year 2012 was a major drought year across the Corn Belt during the period of maximum water use for corn. As illustrated in Fig. 1, in the mid-July of year 2012, during the corn silking stage, most of the Corn Belt suffered from moderate to extreme drought except the eastern part of Minnesota. Especially, severe and extreme drought affected Illinois, Indiana, and eastern region of Iowa. Nebraska is also a major corn producer, but much of its corn crop is usually irrigated using readily available water from the Ogallala Aquifer [17]. According to the USDA NASS data, the total corn planted area of Nebraska in year 2012 is 10,000,000 acres, among which 5,850,000 acres were irrigated [16]. Thus, data from Nebraska were excluded in this study to reduce confounding factor of irrigation. The five selected states have low irrigation rates, and thus it is appropriate to compare corn responses to drought with precipitation data.

2.2 Study Period

Corn is a crop with high water requirements. Moisture stress at any of the corn growth stages, especially the silking period, can cause potential yield reduction. Figs. 2 and 3 show how the growth of corn progresses on weekly basis using percentage emergence and silking rates (data were obtained from NASS Quick Stats 2.0 database [16]). In mid-May of 2012, most corns in the study area emerged in vegetative growth stages (Fig. 2). The silking stage varied from early June to mid-July (Fig. 3). Previous studies have demonstrated that water stress during the silking impedes fertilization and greatly reduces corn yields [8-10]. Thus this present study focused on the phonological stages of corn growth from May to July of year 2012.

2.3 Data

The GHCN-Daily contains daily climate records from over 75,000 stations around the world. Maximum and minimum air temperature, snowfall, snow depth, and daily precipitation are the primary variables

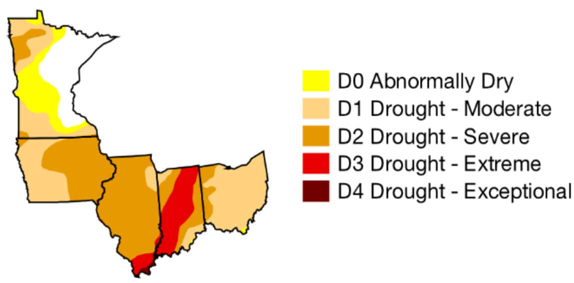

Fig. 1 Drought conditions over the study area in mid-July, 2012. Data were obtained from the U.S. Drought Monitor (http://droughtmonitor.unl.edu).

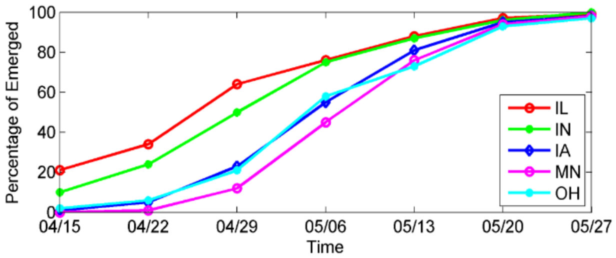

Fig. 2 Weekly corn progress in year 2012 measured in percentage emerged.

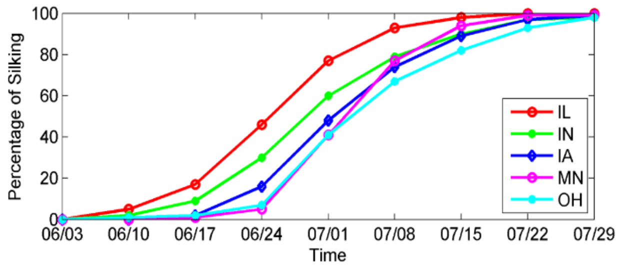

Fig. 3 Weekly corn progress in year 2012 measured in percentage silking.

provided by these stations [15]. GHCN contains the most complete collection of United States daily climate summaries. Precipitation data were obtained from the GHCN-Daily database, in the form of daily precipitation records. Using the latitude and longitude provided for each station, the stations were grouped by county and daily mean precipitation was calculated on a per-county basis.

USDA's NASS provides comprehensive data sets and statistics of crop planting area, yield, production, etc., at county and state levels. In this study, county-level corn planted area, and yield data, and state-level corn growth progress data for the study area were obtained from the NASS Quick Stats 2.0 database [16], using records from annual NASS surveys.

2.4 Method

Corn yields varied locally throughout the study region, likely due to factors such as cultivation practice (planting conditions, fertilizer usage, etc.) and local geographic variation (soil type, climate, etc.). In order to reduce the confounding effect of these variables, the yield anomaly was used as the response variable. The expected yield was calculated by fitting a least-square linear regression line to yield time series data from 1960 to the year preceding the target year (or 1960-2011). For this time period, increases in yield seemed to follow a linear pattern, justifying the use of this method to calculate expected yield. The yield anomaly was calculated as the percentage difference between the projected and observed values.

Total precipitation was calculated for each 8-week interval within corn growth stages in the study year. When measurements were missing, the mean of available precipitation data multiplied by the period length was used if more than half of the values were available; otherwise the county was excluded.

Examination of the data revealed that the relationship between precipitation and yield was non-linear. However, transforming precipitation by taking its base-10 logarithm produced linear relationship between the predictor and response variables, with no clear pattern in the residuals and relatively constant variance around the trend line. Thus, the logarithm of precipitation data was used for analysis in this study.

3. Results and Analysis

Correlation coefficients between $\log_{10}$-transformed total precipitation and yield anomaly were calculated for each 8-week period, as shown in Fig. 4, where x-axis represents center of the 8-week interval, and y-axis indicates correlation coefficients. For 8-week periods centered from early to late June, the correlation coefficients are higher than 0.7. These periods are corresponding to later corn vegetative stages and whole silking stage, in which water supply is critical for corn yield.

The maximum correlation was found for the 8 week period from May 6th to June 30th. In order to quantify the effects of drought, the yield anomaly was plotted against the transformed precipitation for the period of maximum correlation, i.e., the critical period requiring water for corn growth. Least-square linear regression

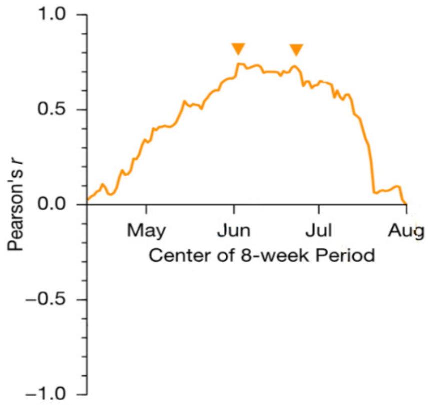

Fig. 4 Pearson product-moment correlation coefficient between $\log_{10}$-transformed 8-week precipitation totals and yield anomaly for different periods 2012. Peak values are indicated with colored triangles.

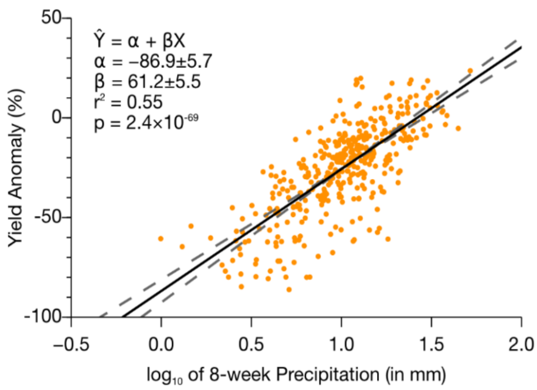

Fig. 5 Least-squares regression for yield anomaly using transformed precipitation (in the period of maximum correlation). The 95% confidence interval for the regression line is shown with dashed lines.

with the transformed precipitation as the predictor variable was used to estimate the impact of low precipitation on yield (Fig. 5). The coefficient of determination (r^2) is 0.55 with p values near 0. So variation in the $\log_{10}$-transformed precipitation during critical period explained 55% variation in corn yield anomaly. The result implies a linear decrease in yield associated with each ten-fold decrease in precipitation over the critical period. Thus, low precipitation during corn growth stages in year 2012 contributed to most reduction of corn yield in the U.S. Corn Belt.

4. Conclusion and Discussion

In this study, precipitation data over corn growth period from later vegetative stage to silking stage were analyzed to assess the impact of drought on corn yield during year 2012 in the U.S. Corn Belt. It is found that precipitation over the period near silking stage of corn development explained 55% variation in corn yield anomaly so water supply near silking stage is critical for corn yield. The strong correlation between precipitation and corn yield anomaly suggests the critical impacts of drought on corn yield in year 2012.

The proposed approach in this paper discovered the quantitative linkage between drought and corn yield, which is critical for accurate assessment of climate impacts on food security. However, precipitation during the identified critical period only explained 55% variation in corn yield anomaly, other factors, such as temperature and length of growing season may also contribute to the variation of corn yield anomaly. Further study to include more factors will be conducted in near future to characterize the impacts of drought in more details.

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Impact of Sea Surface Temperature on COSMO Forecasts of a Medicane over the Western Mediterranean Sea

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Abstract: The paper describes and analyzes the sensitivity of an operational atmospheric model to different SST (sea surface temperature) estimates. The model's sensitivity has been analyzed in a Medicane (Mediterranean hurricane) test case. Numerical simulations have been performed using the COSMO (consortium for small-scale modeling) atmospheric model, in the COSMO-ME configuration. The model results show that the model is capable of capturing the position, timing and intensity of the cyclone. Sensitivity experiments have been carried out using different SSTs surface boundary conditions for the COSMO forecasts. Four different experiments have been carried out: the first two using SST fields obtained from the OSTIA (operational sea surface temperature and sea ice analysis) system, while the other two using the SST analyses and forecasts from MFS (Mediterranean Forecasting System, Tonani et al., 2015; Pinardi and Coppini, 2010). The different boundary conditions determine differences in the trajectory, pressure minimum and wind intensity of the simulated Medicane. The sensitivity experiments showed that a colder than real SST field determines a weakening of the minimum pressure at the vortex center. MFS SST analyses and forecasts allow the COSMO model to simulate more realistic minimum pressure values, trajectories and wind speeds. It was found that MFS SST forecast, as surface boundary conditions for COSMO-ME runs, determines a significant improvement, compared to ASCAT observations, in terms of wind intensity forecast as well as cyclone dimension and location.

Key words: Mediterranean Sea, Medicane, atmospheric model, oceanic model.

1. Introduction

In recent years, the scientific community has started to detect and analyze tropical-like cyclones in the Mediterranean Sea [1]. The Mediterranean is a large and sometimes warm body of water, thus it can be an area of cyclogenesis influenced by convective instability and air-sea interaction, producing cyclones with some of the characteristics of hurricanes [2, 3]. The western Mediterranean Sea is an important cyclogenetic area [4]. These cyclones are characterized by strong winds and a pressure minimum in the middle (calm eye). Such systems are referred in the literature as Medicanes (Mediterranean Hurricanes) and are rare phenomena (only one or two per year) [1, 5].

Since the early 1980s, satellite images have enabled identification and structure analysis of cyclones. The horizontal scale of cyclones ranges from some tens to a few hundreds of kilometers, with typical lifetime of about one to three days.

We analyzed the results of numerical simulations of a Medicane, occurring over the western Mediterranean Sea from 7 to 9 November 2011. The aim was to understand the impact of air-sea interactions in the maintenance/formation and the characteristics of the cyclone. In recent hurricane-like cyclones in the Mediterranean, convective instability has been shown to play an important role [6]. The means by which convective instability is produced has been the subject

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of many numerical studies examining the role of heat and moisture fluxes rising from the Mediterranean Sea. Some numerical experiments [7] illustrate that both the surface heat and moisture fluxes are fundamental for this type of hurricane-like cyclogenesis and they play also an important role in the subsequent development of the cyclone. Sensitivity simulations [8] have highlighted the sea-air fluxes role in the formation of the storm as well as the strong influence of the latent heat release associated with convective motions during its mature stage. It has been hypothesized [9] that a hurricane-like cyclone can intensify in a similar way to tropical cyclones.

2. The Meteorological Events

On 3 November 2011, a wide trough between the British Isles and the Strait of Gibraltar produced a pressure minimum near Ireland (Fig. 1a). The following day, the trough moved eastward, approaching the southern Mediterranean Sea and its axis tended to rotate counter-clockwise, resulting in a split of the jet bordering the trough. On November 5, the low pressure of the trough almost split into an isolated minimum, slowing down its eastward motion (Fig. 1c), while an ascending branch of the polar jet, associated with a negative anomaly in the high tropopause, was further displaced toward the central Mediterranean (not shown). This baroclinic structure caused a marked area of instability in the central Mediterranean. On November 6, the cyclonic depression disengaged completely from the main mid-latitude westerly jet producing a low cut-off between the Balearic Islands and Sardinia (Fig. 1d). On November 7, the minimum pressure tends widened horizontally and took on an increasing barotropic structure, with the cloud cover having the typical characteristics of tropical-like cyclones. Fig. 2 shows the cloud cover evolution captured by the Meteosat 9 satellite images in the IR channel (10.8 micrometers).

These satellite images show the persistence of the vortex throughout the first 12 hours of November 9, when the Medicane progressively loses its intensity and expires in the Gulf of Lyon.

The NOAA SSD (Satellite Service Division) categorized this system as a 01M tropical storm (http://www.ssd.noaa.gov/PS/TROP/DATA/2011/tdata/med/01M.html) to indicate that the cyclone is "almost perfectly barotropic" and that the Mediterranean Sea basin is capable of developing this type of cyclone.

3. COSMO and MFS

The meteorological event described was simulated using the COSMO (consortium for small-scale modeling) atmospheric model which is a limited-area, non-hydrostatic forecasting model (http://www.cosmo-model.org/). It was designed both for operational numerical weather prediction and various scientific applications at meso-β (20-200 km) and meso-γ scales (2-20 km). The basic version of the COSMO model was designed at the German weather service (DWD) and developments are carried out within the consortium formed by the national meteorological services of seven European countries:

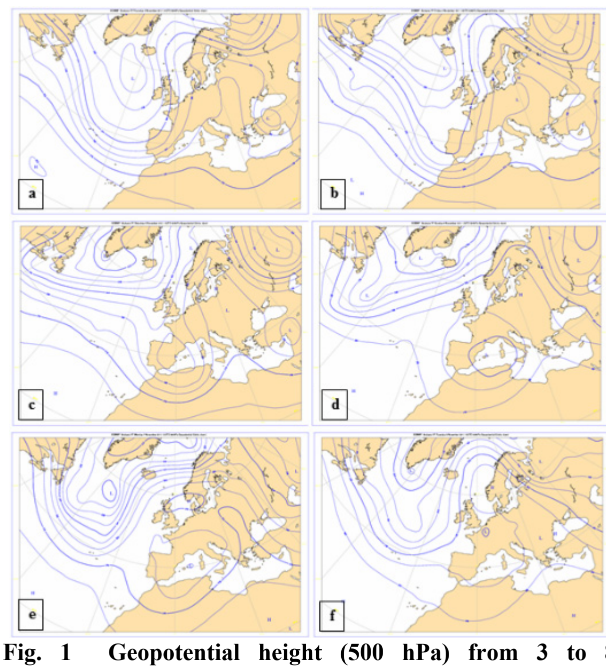

Fig. 1 Geopotential height (500 hPa) from 3 to 8 November 2011 by ECMWF analyses at 12:00 (corresponding to a), …, f) panels).

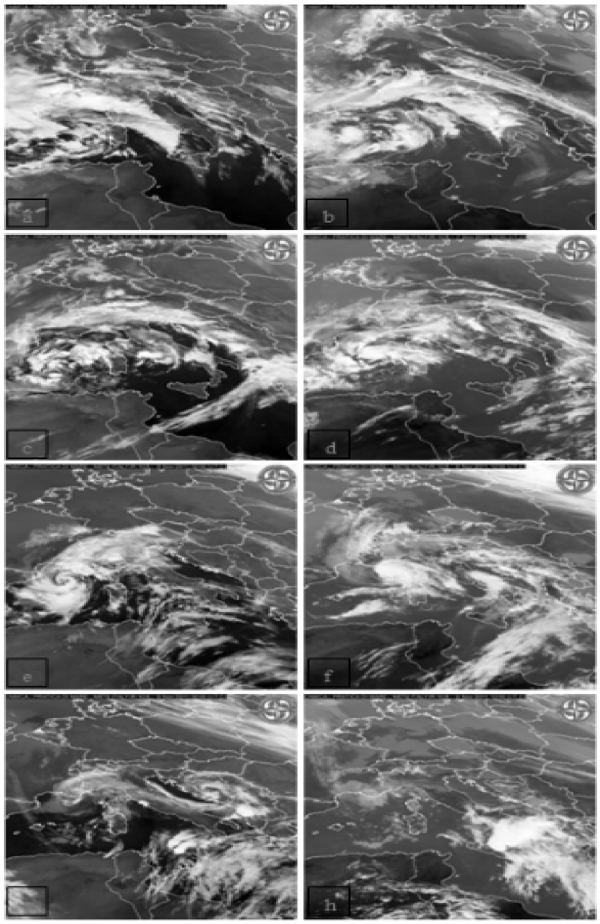

Fig. 2 Meteosat 9 satellite observations in the infrared channel (10.8 micrometers) from 00:00 UTC on 6 November to 12:00 UTC on 9 November every 12 hours (corresponding to a), …, h) panels).

Germany, Greece, Italy, Poland, Romania, Russia and Switzerland. Operational applications of the model within COSMO mainly have a grid spacing of 1/16° (about 7 km).

The Italian Meteorological Centre (CNMCA) uses the configuration COSMO-ME which covers most of Europe (Fig. 3) with a horizontal grid of 7 km and 40 vertical levels with a top at about 22 km. The model's time integration step is 60 seconds. The operational integration of COSMO-ME is driven by the boundary conditions provided by the IFS (integrated forecast system) global model of ECMWF and is initialized with atmospheric analysis fields produced by the LETKF ensemble data assimilation system implemented at CNMCA [10, 11]. Both IFS and COSMO-ME use optimally interpolated SSTs (sea surface temperatures)

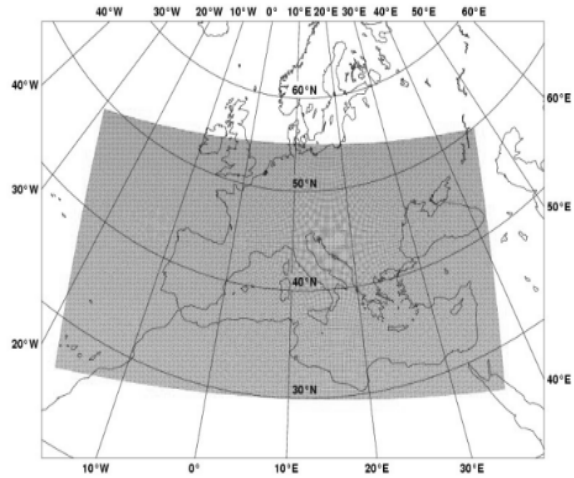

Fig. 3 Domain of the COSMO model in the COSMO-ME configuration.

from the OSTIA system (Operational Sea surface Temperature and sea Ice Analysis [12]), which includes satellites and in situ data. The initial SST fields are kept constant as boundary conditions during the COSMO-ME forecast time.

In this paper, SST forecast fields produced by the MFS (Mediterranean forecasting system) will be also used as initial and boundary conditions. MFS (http://medforecast.bo.ingv.it/) is an operational forecasting system [13-15] consisting of a near real-time observation system with satellite and in situ elements, a numerical ocean forecasting model at a basin scale, based on a primitive equation model [16, 17], and a data assimilation scheme [18]. The MFS spatial domain is shown in Fig. 4. The numerical ocean model has a resolution of 1/16° × 1/16° on the horizontal and 72 unevenly spaced vertical levels [16]. The system produces daily ten-day ocean forecasts and ocean analyses using a daily assimilation cycle [19, 20] where a different optimally interpolated SST from satellites [21] is used to constrain the model surface temperature.

4. Event Description Using COSMO-ME Forecasts: Dynamics, Heat Fluxes and Thermal Structure

COSMO-ME forecasts were used to detect the main features of the vortex and its intensity from initial stages. To classify the type of cyclone, the expected wind speed at 10 meters and in particular the maximum speed value in the area was considered. We refer to the modified Saffir-Simpson hurricane wind-scale (http://www.nws.noaa.gov/directives/sym/pd01006004curr.pdf) to classify the cyclone.

The best estimate of maximum forecast wind was obtained from three different 00 UTC operational runs of the model for 6, 7 and 8 November (Fig. 5).

The Medicane can be classified as a tropical storm, with maximum winds between 18 and 32 m/s in its mature phase. The most intense phase of the vortex lasted for about two and a half days from 00:00 UTC on November 7 to 12:00 on November 9. The evolution of the Medicane was characterized by a growth phase of about 40-44 h, during which the maximum intensity of the wind increased from 18 to 28 m/s, and by a more rapid decrease of approximately 16-20 hours

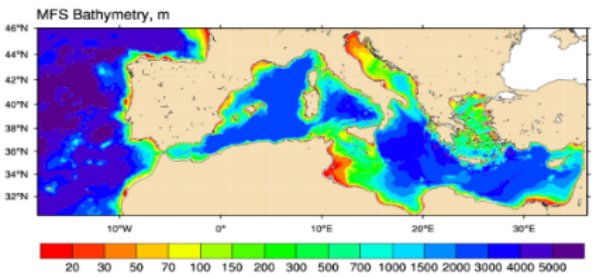

Fig. 4 Domain and bathymetry (m) of the MFS model configuration.

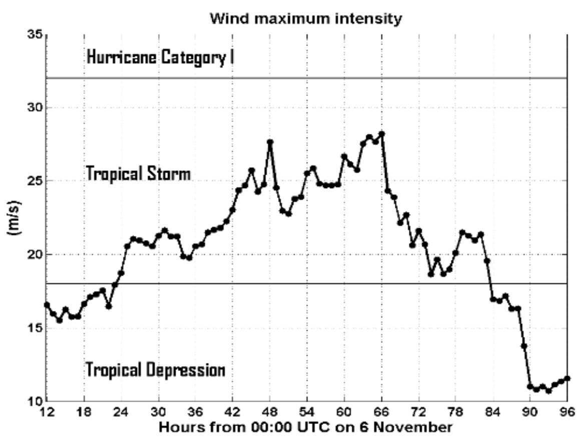

Fig. 5 Wind maximum intensity (m/s) from 12:00 UTC on 6 November to 00:00 UTC on 10 November. Black horizontal lines mark the separation between different categories: tropical depression, tropical storm and hurricane category I.

with a maximum intensity that returned below the threshold of 18 m/s.

The vortex trajectory was also calculated considering the minimum pressure for the same period. The cyclone became a tropical storm from the first hours of the day on November 7, in the area south of the Balearic Islands. Initially, the vortex moved from the Balearic Islands to the north-east; thus it moved in an irregular manner between parallels 41°-42° for several hours.

The minimum pressure was about 994 hPa at 15:00 UTC on 8 November. Finally, it moved a north-west towards the Gulf of Lyon where, approaching the coast, it gradually lost its intensity and died out. The intensity of air-sea latent and sensible heat fluxes was linked to differences between the SST and the low level atmospheric air temperature.

In the vortex growth phase, the sea surface was quite warm, up to 21-22 °C in the area south of the Balearic Islands (Fig. 6, medium and bottom panel). For the same period, the 10-meters air temperature, as obtained by LETKF data assimilation system, was between 17 °C and 20 °C (Fig. 6, top panel), creating an air-sea temperature difference of 1-5 °C.

The temporal variability of the air-sea temperature differences was monitored from data collected by the Dragonera buoy (Lat. = 39.56 °C; Lon. = 2.11 °C) from Puertos del Estado (Spain) [22]. The SST values measured from buoy are consistent with the SST forecast values produced by MFS (Fig. 7).

This notable air-sea temperature difference created large heat fluxes from the sea surface, which thereby maintained the vortex. The vertical thermal structure of the cyclone was characterized by a surface warm core, which is a characteristic structure of tropical-like cyclones (Fig. 8).

5. SST Sensitivity Studies: Trajectory and Heat Fluxes

In order to assess the impact of different SST estimates on the formation and maintenance of the vortex itself, four different simulations were performed using COSMO-ME (Table 1).

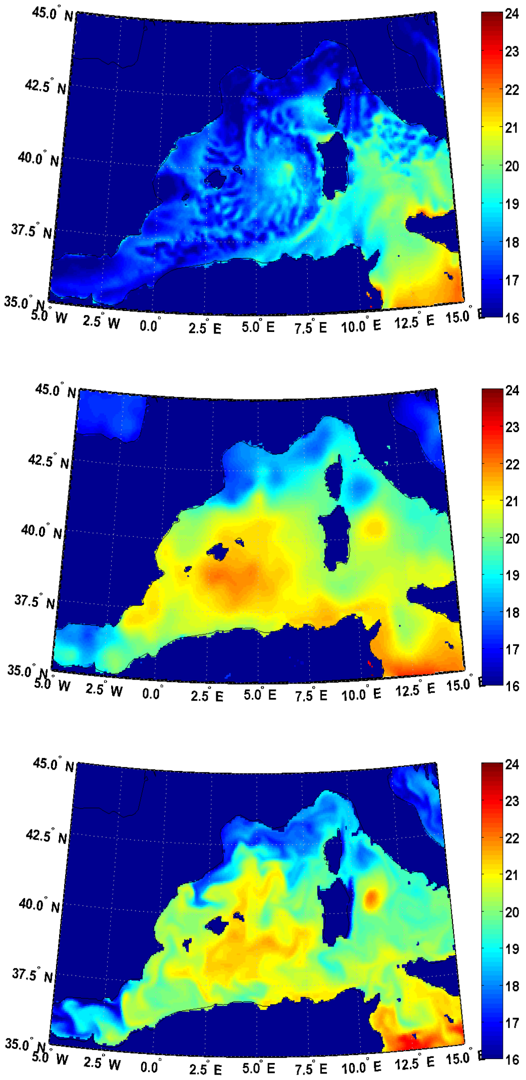

Fig. 6 Air temperature at 10 meters obtained by LETKF data assimilation system (top panel), SST field by OSTIA system (medium panel) and by MFS system (bottom panel) at 12:00 UTC on 7 November.

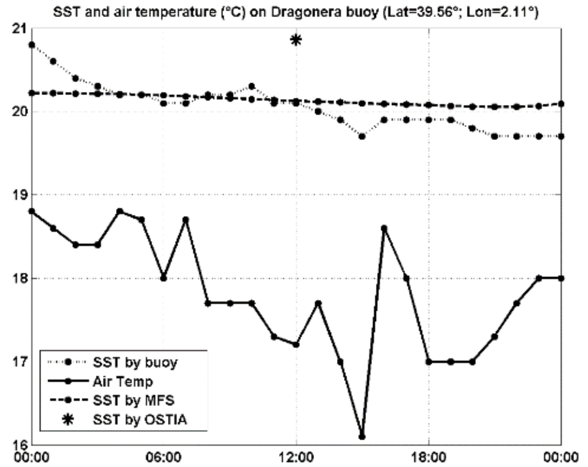

Fig. 7 Air temperature at 2 meters (°C) and SST (°C) observed by the Dragonera buoy (continuous and dot lines) for 7 November 2011. SST means on the box (0.25 × 0.25 deg) centered at Dragonera buoy position, by MFS (dash line) and OSTIA systems (star).

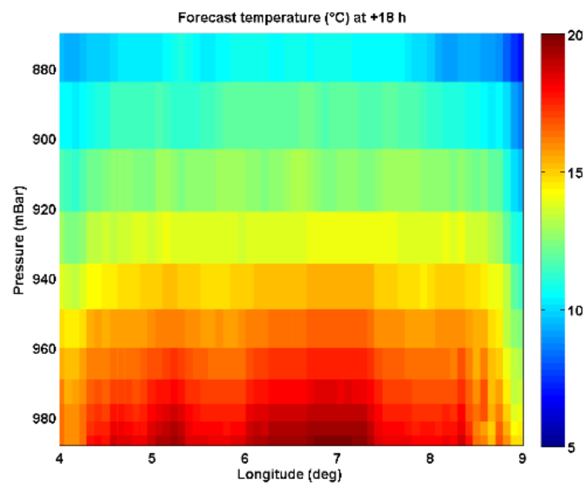

Fig. 8 Temperature (°C) vertical section along parallel 40.0 °C at hour 18:00 UTC on 7 November by COSMO-ME run at 00:00 UTC on 7 November.

Table 1 Configurations of the four different numerical experiments. Simulations started at 00:00 UTC on 7 November 2011 and lasted for 72 h.

Experiments	SST boundary conditions
EXP1	SST from Ostia (default configuration)
EXP2	SST fields by Ostia lowered by 2 °C
EXP3	SST fields from MFS (fixed to initial values)
EXP4	SST fields from MFS (variable)

An initial simulation was carried out with the COSMO-ME operational settings (EXP1) where the OSTIA initial condition SST are persisted as boundary conditions throughout the forecast time. In the second experiment (EXP2), the OSTIA SST field was uniformly lowered by two degrees Celsius over the domain and the same settings of EXP1 were used. In EXP3, the MFS initial analysis SST field was used and kept fixed as surface boundary conditions throughout the forecast time. In the last experiment (EXP4), the MFS forecast SST fields were imposed every three hours and linearly interpolated for each model time step during the COSMO-ME forecast time.

The Medicane trajectory, defined as the position of the pressure minimum, was monitored for 48 hours starting from 12:00 UTC on November 7, at six hours intervals, until 12:00 UTC on November 9. Trajectories resulting by EXP1, EXP2, EXP3 and EXP4 experiments are shown in Fig. 9 with respect to the NOAA trajectory analysis (http://www.ssd.noaa.gov/PS/TROP/DATA/2011/tdata/med/01M.html).

The forecast trajectory for the first 24 hours is quite similar for all four experiments (Fig. 9) and the difference respect to NOAA analysis is contained in 30-40 km (Fig. 10).

The trajectories for experiments EXP3 and EXP4 deviate significantly from the EXP1 trajectory for the next 24 hours, better reproducing the NOAA analysis, with a maximum difference of about 100 km. Thus, EXP3 and EXP4 trajectories are significantly different, compared to EXP1, in the Gulf of Lyon area. Such differences are attributable to the different SST fields used as boundary conditions for the COSMO-ME model (see also Fig. 6). The average SST in the Gulf of Lyon is 16.7 °C and 18.8 °C for experiments EXP1 and EXP3, respectively (domain of average: 41° < Lat. < 44°, 3.0° < Lon. < 7.0°). This temperature difference of about 2 °C determines notable differences in surface heat fluxes.

COSMO-ME latent and sensible heat fluxes are displayed for the four different experiments on the previous spatial area in Fig. 11, where the negative values indicate heat flux from the sea to the air. Heat fluxes for EXP2 are much smaller than in the reference EXP1 due to the smaller absolute value of SST imposed. There is a difference up to 100 W/m^2 and 35 W/m^2 for latent and sensible heat fluxes, respectively. Heat fluxes of EXP3 and EXP4 were substantially more intense than in EXP1 for the last part of the meteorological event. There is a difference up to 50 W/m^2 and 8-10 W/m^2 for latent and sensitive heat fluxes, respectively.

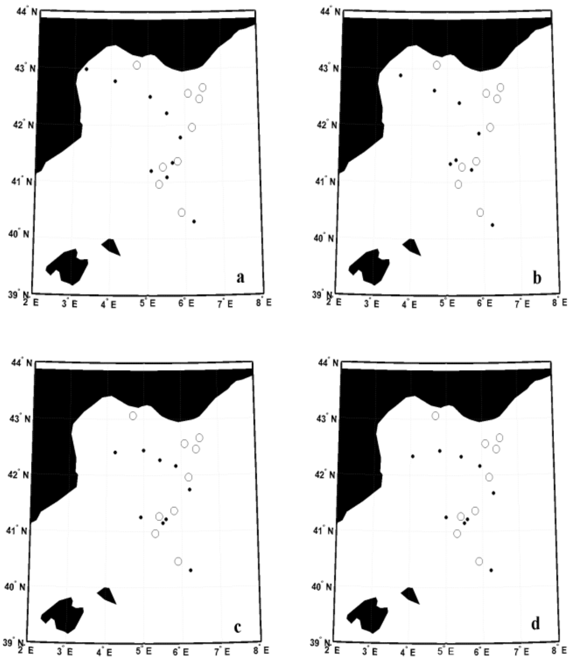

Fig. 9 Trajectories from 12:00 UTC on 7 November every 6 h until 12:00 UTC on 9 November, for the four different COSMO experiments with respect to the NOAA analysis: EXP1 (a), EXP2 (b), EXP3 (c) and EXP4 (d).

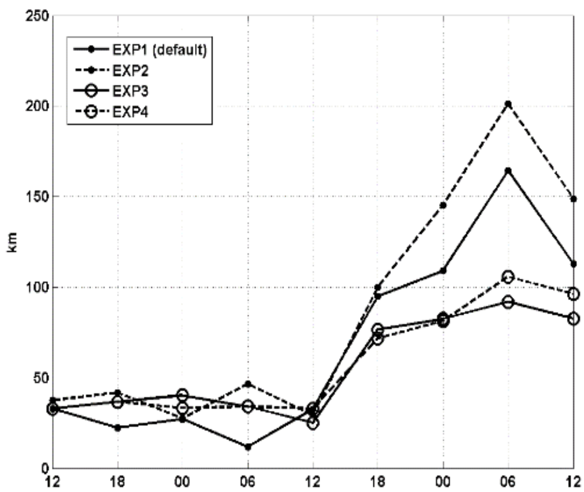

Fig. 10 Distances (km) of the pressure minimum positions respect to NOOA analysis, every 6 h from 00:00 UTC on 7 November.

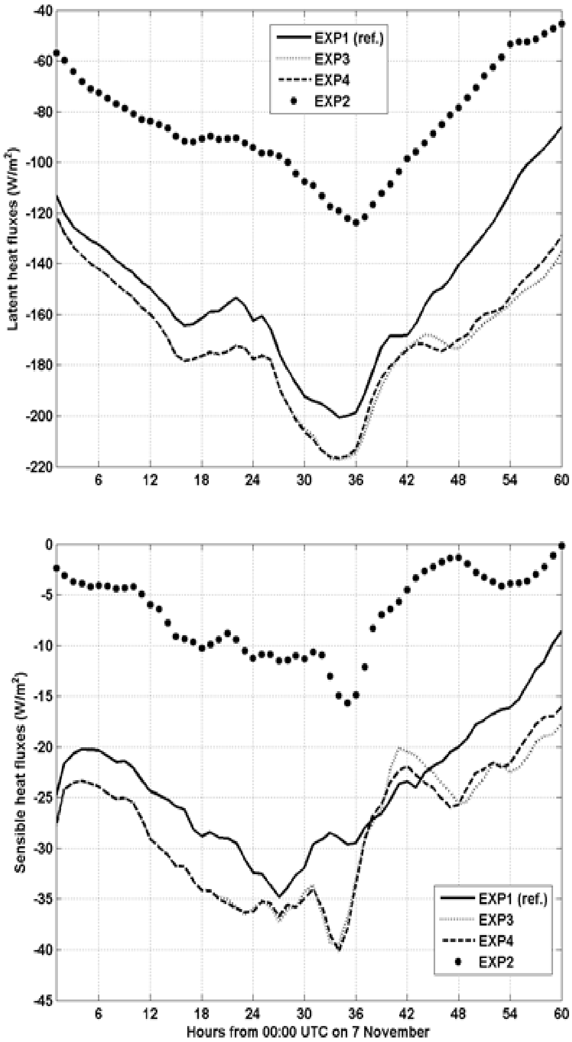

Fig. 11 Latent (top) and sensible (bottom) heat fluxes for the four experiments, averaged on domain 41° < Lat. < 44°, 3.0° < Lon. < 7.0°, every 1 h from 00:00 UTC on 7 November.

The larger energy released from the sea surface, and probably the different SST field structure in the Gulf of Lyon for experiments EXP3 and EXP4 led to a strengthening of the vortex itself and a different trajectory for the last hours of the meteorological event.

The pressure minimum was also monitored for 48 hours (Table 2). The experiments EXP3 and EXP4 reproduce pressure values closer to those obtained from NOAA analysis throughout the all considered period. Also, they are always minor compared to EXP1, indicating that in fact the vortex has a higher power respect to the control experiment, especially in the final phase of the weather event.

6. SST Sensitivity Studies: Pressure and Wind Intensity

In this section we analyze the forecast pressure and wind fields for the four different experiments. The forecast step +45 h, valid at 21:00 UTC on November 8 was considered to coincide with the cyclone maximum strength and intensity. The results are reported in Figs. 12 and 13 for pressure and wind, respectively.

A colder SST in EXP2 determined a lower minimum pressure (compare 12b with 12a), as expected. In EXP3 and EXP4, the minimum pressure was lower (about 996 hPa for both) than in EXP1 due to the different but warmer MFS forecast SST in the area around the Gulf of Lyon. Smaller pressure differences were found between EXP3 and EXP4 experiments.

Wind speed fields were clearly linked to the pressure fields and followed their structures and evolution (see Fig. 13). The wind field was much less intense in EXP2, compared with the control experiment. In EXP3 and EXP4 the vortex appeared more intense, with a smaller calm eye and asymmetric wind intensity around it.

The forecast wind speed can be compared with satellite wind estimates by ASCAT (Advanced SCATterometer) sensors on board the MetOp-A satellite (http://www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Meteorological_missions/MetOp).

The wind forecast was valid at hour 21:00 UTC on 8 November (Fig. 13), while the satellite crossing (Fig. 14) was about 20 minutes before (exactly at 20:39 UTC). ASCAT wind intensity estimates indicated a velocity up to 21-23 m/s. The spatial resolution of satellite measurements was 12.5 × 12.5 km^2.

The position and the size of the Medicane were computed for the various COSMO experiments, at

Table 2 Pressure minimum by the four different numerical experiments and NOAA analysis.

	12	18	00	06	12	18	00	06	12
EXP1	1001	1001	999	999	1000	1001	1003	1006	1010
EXP2	1002	1003	1001	1002	1003	1006	1010	1013	1016
EXP3	1001	1001	998	997	996	995	996	999	1002
EXP4	1001	1001	998	997	996	995	997	1000	1003
ANALYSIS	-	997	991	991	991	991	991	1000	1006

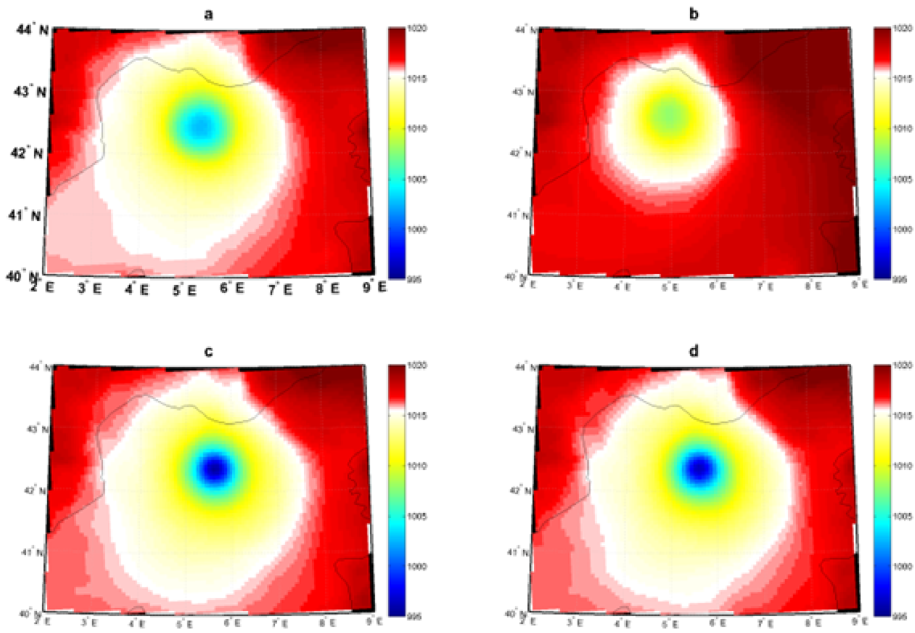

Fig. 12 Forecast mean sea level pressure (hPa) at 21:00 UTC on 8 November for EXP1 (a), EXP2 (b), EXP3 (c) and EXP4 (d) experiments.

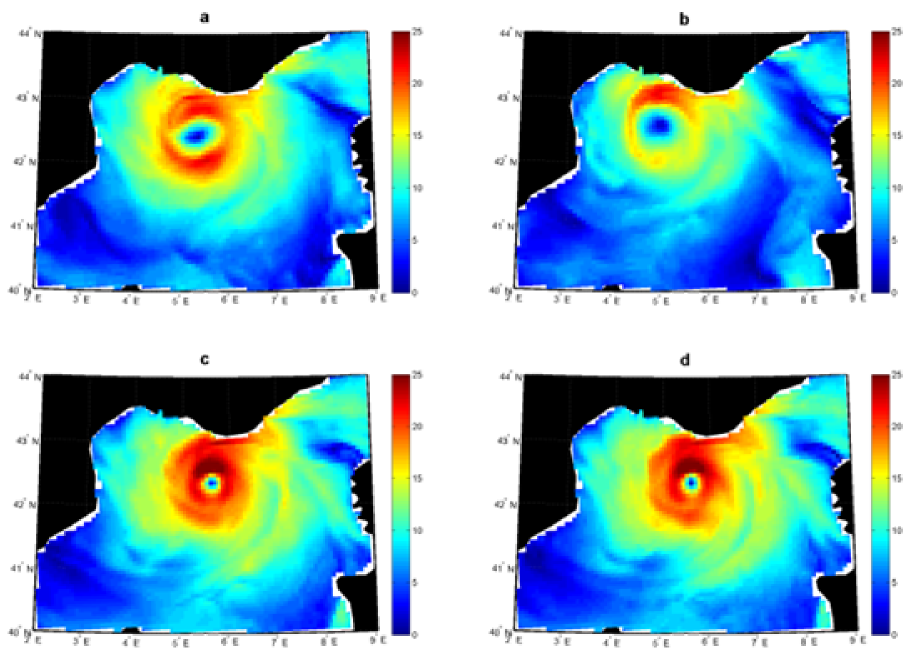

Fig. 13 Forecast wind intensity (m/s) at 21:00 UTC on 8 November for EXP1 (a), EXP2 (b), EXP3 (c) and EXP4 (d) experiments.

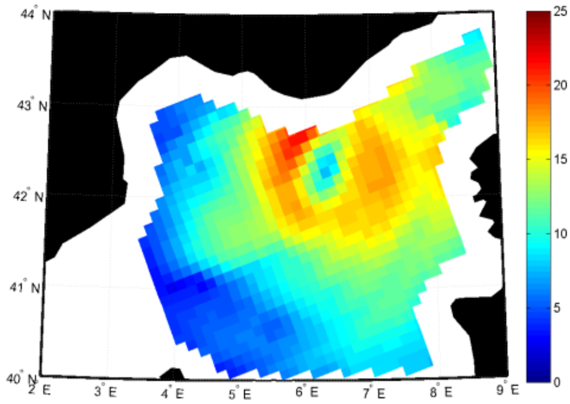

Fig. 14 Wind intensity estimate (m/s) from ASCAT sensors on board of MetOp-A satellite at 20:39 UTC on 8 November 2011.

21:00 UTC, and compared with the ASCAT measurements. The size of a tropical-like cyclone is difficult to define objectively; different definitions are currently used by researchers and operational weather forecasters [23]. In the following, the cyclone size was defined as the radius of the area with wind speeds larger than 15 m/s.

For EXP1, EXP3 and EXP4, the mean sizes were similar, in the range 125-130 km (see Table 3) consistent with the ASCAT data if an error corresponding to the 12.5 km bins is considered for ASCAT and the grid size of 7 km for the COSMO-ME data. The difference in longitude was about 1 deg for EXP1 but only 0.6 deg for EXP4 and the ASCAT estimate. Thus mean size and position of the cyclone are best depicted by EXP4.

To characterize the wind horizontal structure, Fig. 15 shows normalized histograms of wind intensity at 21:00 UTC on November 8 for the region of the Gulf of Lyon. The wind intensity is subdivided into classes of 1 m/s and the number of events is reported as a percentage with respect to the total number of events.

The modal values are 11, 13 and 16 m/s respectively for EXP1, EXP4 and ASCAT. The histogram for EXP1 is wider and more symmetric than EXP4 and ASCAT, with a modal value that occurs in about 10% of the cases (14% and 13% for the EXP4 and ASCAT, respectively). ASCAT data show a smaller tail for high values of wind speed. In general, the comparison shows that the velocity distribution in EXP4 is more similar to ASCAT.

7. Conclusions

A sensitivity study of an operational atmospheric forecast model, COSMO-ME, with different SST estimates and impositions was carried out. The sensitivity of the model was studied for a Medicane (Mediterranean Hurricane) test case, observed over the western Mediterranean Sea from November 7 to 9, 2011. ASCAT wind estimates by MetOp-A satellite indicated an intensity up to 21-23 m/s. Four different forecasts, using different SST fields, were carried out with the COSMO atmospheric model. The operational SST used as initial surface and boundary conditions from OSTIA optimally interpolated analyses (EXP1) was compared with SST from MFS analyses (EXP3) and forecasts (EXP4). The numerical simulations identified the most intense phase of the vortex from 00:00 UTC on November 7 to 12:00 on November 9, for about two and a half days. For this period, the Medicane can be classified as a tropical storm with maximum winds between about 20 and 30 m/s.

The different SSTs impacted the trajectory of the vortex, changing its direction especially in the last part

Table 3 Positions and sizes of the Medicane for the four COSMO-ME experiments (at 21:00 UTC) and for the ASCAT satellite measurements (at 20:39 UTC).

Experiments	Lat (deg)	Lon (deg)	Mean radius (km)
EXP1	42.405°	5.342°	126
EXP2	42.577°	4.989°	117
EXP3	42.352°	5.601°	128
EXP4	42.352°	5.601°	129
ASCAT	42.230°	6.285°	144

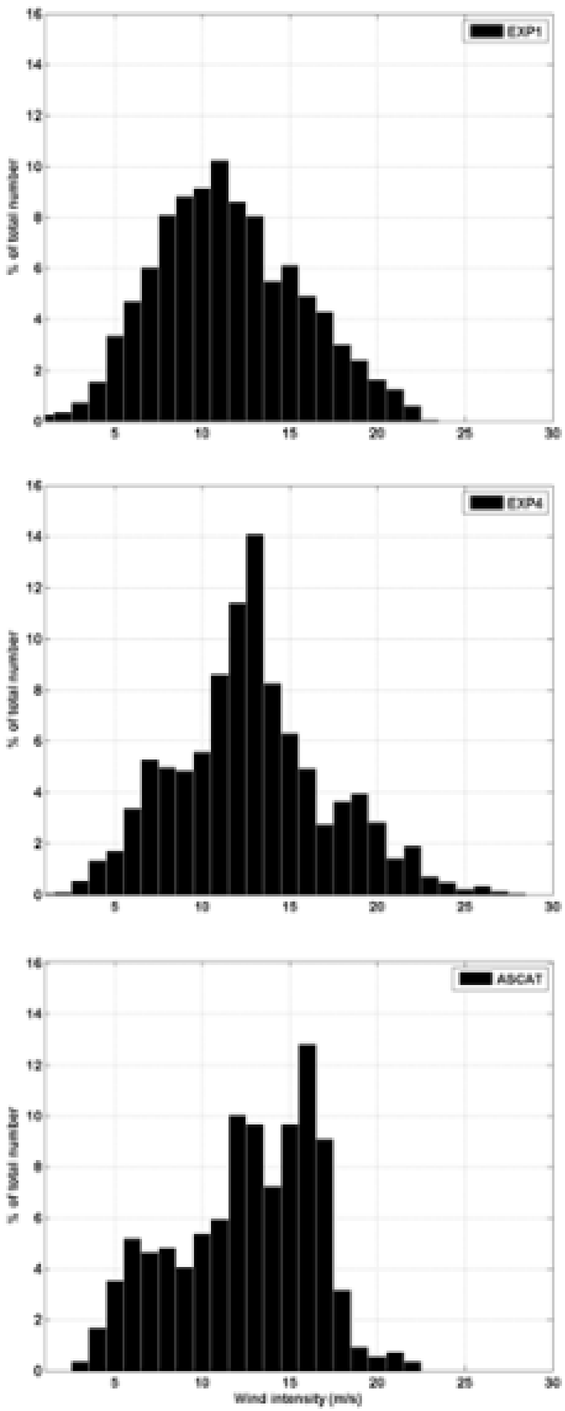

Fig. 15 Histograms (% of total number) of wind for EXP1 (top), EXP4 (middle) and ASCAT (bottom) at 21:00 UTC on 8 November for the model and 20:39 UTC for the ASCAT observations.

of the meteorological event, with EXP3 and EXP4 better reproducing the NOAA trajectory analysis.

Latent and sensible heat flux intensities varied up to 10 and 50 W/m^2 respectively, in the experiments EXP1, EXP3 and EXP4. The major heat fluxes in EXP3 and EXP4 determined a minimum pressure lower than in EXP1, according with NOAA analysis.

The wind intensity and its horizontal distribution is however the major difference between EXP1 and EXP4, with the latter better reproducing the ASCAT data. The mean size of the vortex, in the range of 125-130 km, was quite similar between the experiments EXP1, EXP3 and EXP4.

Our results highlight that the type and value of the SST boundary conditions play an important role in determining the distribution of forecast wind velocities, minimum pressure and location of the cyclone eye. A three-hour forecast SST from the operational MFS ocean forecasting model seems to increase the accuracy of Medicane forecasts with respect to all other measurements currently available.

Acknowledgments

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Building an Ecological Civilization in China: Towards a Practice Based Learning Approach

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Abstract: The adoption by the 18th Congress of the Communist Party of China in November 2012 of a policy on ecological civilization is a landmark event for the nation and the world community. China's vision for building an ecological civilization is comprehensive, multi-sectoral and systemic and is intended to direct and balance progress among ecological, economic, social, cultural and political dimensions of change. Some on-going efforts and potential future activities that meet China's vision of an ecological civilization are described. Establishment of dedicated ecological civilization areas for experimenting with legal, regulatory and administrative incentives that would facilitate the march towards the ideal is encouraged. Chinese biosphere reserves which are designated with the explicit aim of building harmony between humans and nature would be suitable candidates for designing and developing such dedicated ecological civilization areas.

Key words: Ecological, civilization, experimental, learning, biosphere.

1. Introduction

The commitment to build an ecological civilization has emerged strongest, and is now government policy in China, the country with the largest (about 19%) of the world's population. China cherishes its memory of more than 5,000 years of living relationship between its people, land and the environment. At the same time it is a nation where the pace of industrial progress and economic growth over the last three decades has compressed changes that spanned centuries in other industrialized nations of the world. China has been referred to as a civilizational state, in contrast to nation states that spearheaded the industrial civilization two centuries ago, by Chinese [1] as well as western [2] scholars.

Felipe Fernandez-Armesto [3] defines civilization as a relationship to the natural environment. The civilizing impulse is driven by an ambition to re-engineer the natural environment to meet human demands. He points out that civilization is a relationship between a single species, i.e. *Homo sapiens sapiens,* and the rest of nature. Kai [4] writing in *Qiushi,* the organ of the Central Committee of the Communist Party of China noted that the term "ecological pertains to the state in which nature exists, whereas the term civilization refers to a state of human progress. Thus ecological civilization describes the level of harmony that exists between human progress and natural existence in human civilization." In China there is growing concern at the highest levels of the leadership that the balance between the ecological and material dimensions of civilization may have tilted sharply against the ecological.

Like civilization, ecology is a relational term; it is the study of the relationship between living things and their environments. The German zoologist Ernst Haeckel (1834-1919) coined "ecology" borrowing from the Greek *oikos*—a house, dwelling place or habitation, and *logos*—"logical" or persuasion

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through the use of reason, respectively. Since the first human landing on the moon and the rapid rise in the number of satellites circling planet earth we are increasingly aware of the "wrongs" we have inflicted upon nature. But, as the impasse in international climate change negotiations in recent years has shown, our ability to "right" our "wrongs" is a challenging task even when nations agree, in principle, on the urgency for action.

The aspiration-achievement gap is common to programs and initiatives that attempt to address and solve environment and development problems at global and national scales. A synthesis of more than 60 national reports prepared for the Rio+20 Summit on Sustainable Development convened in Brazil in June 2012 by UNDP (United Nations Development Program) and UNDESA (UN Department of Economic and Social Affairs) noted: "Today's challenge is chiefly implementation. The evidence from the reports is overwhelming that a gap exists between stated commitments to sustainable development and the reality of implementing sustainable development policies and programs in all countries and regions reviewed" [5].

China is a country with a governance system whose evolution is time-tested and continuing. The last 3 decades of rapid economic growth and progress in industrial, science and technology development has made China a society with significant inequalities in social, economic and environmental wellbeing of its people. There are large tracts in western China that aspire towards the economic prosperity already attained by the eastern provinces. China's commitment to an ecological civilization faces the challenge of convincing a vast majority of its people and administrators that the growth model of the past three decades that pulled millions out of poverty and made China the second largest economy in the world must now be exchanged for an alternative whose contours remain vague and demands changes that have not been tested elsewhere at scales appropriate to a vast and populous country as China.

In this paper, we advocate a practice based approach that will promote experimentation and learning in the construction of an ecological civilization in China. Although the strategic vision is national, experimentation and learning must begin at local and context-specific scales. China may consider establishing a number of special areas, similar to those dedicated to free trade, exclusive economic development etc., that have been part of China's drive for rapid development over the last three decades, dedicated for experimenting with regulatory, policy and market measures for guiding institutional and behavioral adaptations for the transformation towards an ecological civilization. A pilot network of places chosen from the CBRN (Chinese Biosphere Reserve Network) (Fig. 1) could constitute such a set of dedicated areas for supporting the emergence of an ecological civilization. CBRN includes sites that are part of the World Network of Biosphere Reserves of UNESCO (United Nations Educational Scientific and Cultural Organization) and thus would attract interested individuals and institutions from other parts of the world that are keen to engage with, contribute to and learn from the bold endeavor that China has embarked upon.

2. An Overview of China's Vision for an Ecological Civilization

Gaoli [6] provides a comprehensive view of China's vision in promoting ecological progress leading to the emergence of an ecological civilization. We have summarized six principles and related guidelines as well as important facts and issues that must be addressed to promote ecological progress as envisaged by Gaoli [6] (Table 1). The author stresses: "Building an ecological civilization does not mean that we must abandon industrial civilization and return to primitive ways of living. Rather, it means building a civilized society with developed production, affluent standards of living, and sound ecological environments

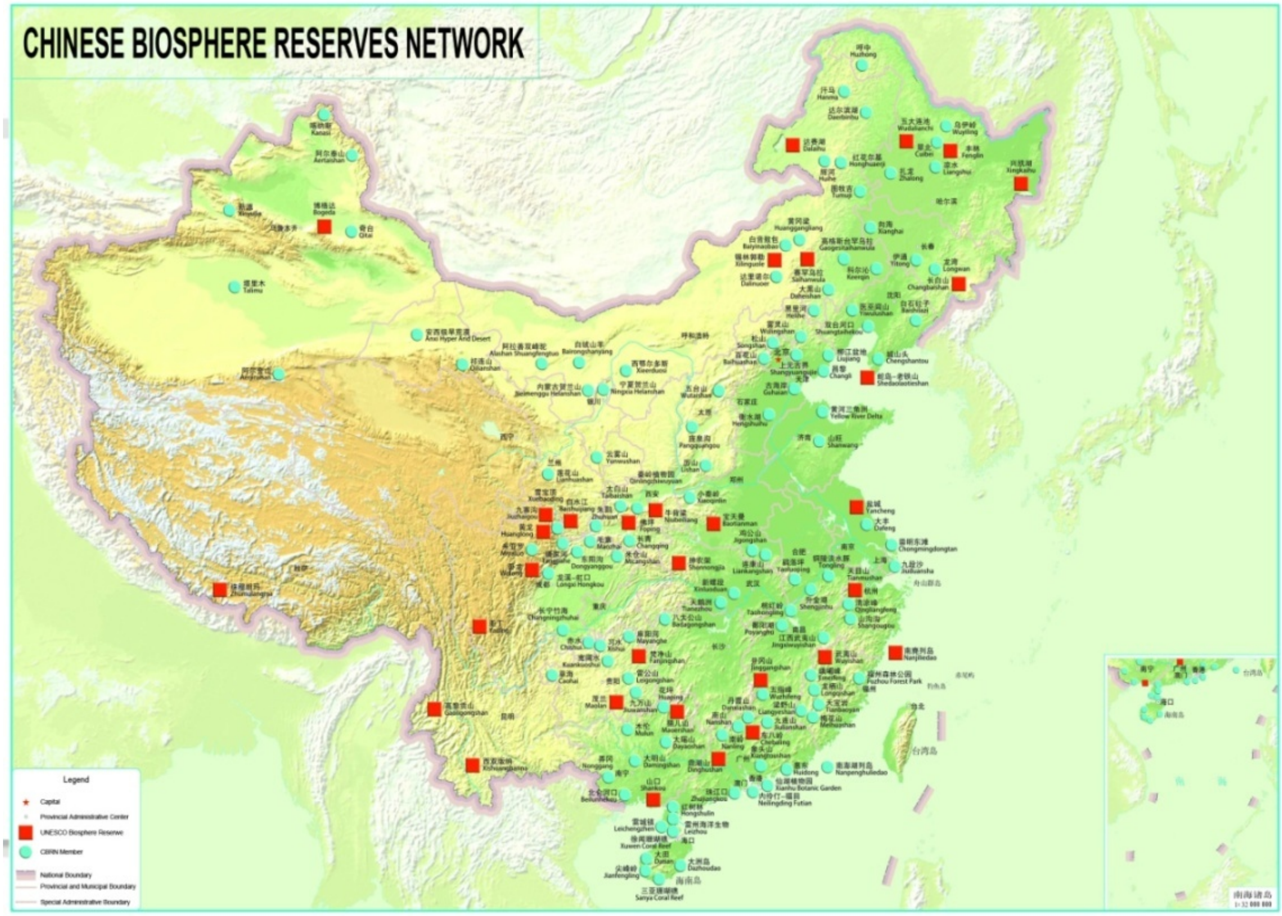


Fig. 1 A map showing the distribution of biosphere reserves that are part of the CBRN (Chinese Biosphere Reserve Network) as of 1 January 2015. 32 of them marked in red squares are recognized by UNESCO's Man and the Biosphere (MAB) Program as world biosphere reserves.

in accordance with the goals of realizing sustainable development and achieving a state of balance between nature and humans." This view resonates with other policy prescriptions of multilateral financial institutions for China; for example, in its vision for China 2030 [7], the Bank urges China to "grow green"; "instead of considering environmental protection and climate change mitigation as burdens that hurt competitiveness and slow growth…green development could become a significant growth opportunity." Building an ecological civilization is hence a challenge in engineering and sustaining harmony among economic, social, environmental, cultural and political trajectories of change.

In adopting the notion of ecological civilization at its 18th Congress in November 2012, the CPC (Communist Party of China) placed ecological progress on par with economic, political, cultural and social ones and formulated an agenda to develop socialism with Chinese characteristics [6, 8]. There is some parallel between CPC's visioning of an ecological civilization and international emphasis on economic, environmental and social pillars of sustainable development adopted by nation states at the World Summit on Sustainable Development convened in Johannesburg, South Africa in 2002. Since then, organizations, such as the UCLG (United Cities and Local Governments) have built on UNESCO's Universal Declaration on Cultural Diversity [9] and the Convention on the Diversity of Cultural Expressions [10] and called for the recognition of culture as a fourth pillar of sustainable development [11]. To

Table 1 Progressing towards an ecological civilization in China (summarized and adapted from Ref. [6]).

	Six basic principles of ecological progress	Important guidelines for attaining the principle	Facts and issues linked to the principle and guidelines for ecological progress in China
1	Optimizing spatial planning on the basis of functional zones.	Firm commitment to a strategy of functional zoning; make urbanization more intensive, intelligent, green and low carbon; China to become a leading maritime nation.	In the "years ahead" more than 100 million people are expected to leave the countryside and take up residence in urban areas; the four "red-lines" of ocean development—no damage to ecological balance, no undermining of ecological functions, no changes to basic properties and no further deterioration of already damaged ecosystems.
2	Effectively reducing pressure of economic activities on resources and environments through efforts to adjust and optimize industrial structures.	Dissolving excess production capacity; transformation and upgrading of industries; underpinning the role scientific and technological improvements in promoting ecological progress; devote significant efforts to develop circular economies.	Prohibit approval of new projects that will increase production capacity in industries where there is serious excess capacity; some sectors should be suppressed and others allowed to grow; ecological transformation of agricultural, industrial and service sectors; devotion of greater efforts to research and development; reduction, reutilization and recovery with emphasis on reduction; "Ten-Hundred Thousand" schemes to showcase circular economies through a series of demonstration projects.
3	Comprehensive enhancement of resources conservation in order to transform the way resources are utilized.	Conserve energy, reduce emissions, and lower consumption; step-up efforts to use water, mineral and land resources economically.	Non-negotiable target of cutting emissions of ammonia nitrogen and nitrogen oxides by 10%; "10,000 Enterprises Energy Efficiency and Low Carbon program"; three "red-lines" in the use of water—controlling exploitation; controlling efficiency of use; and prevent pollution; improve mineral recovery rate by 20% to reach international standards; maintain the minimum of 120 million hectares of arable land to guarantee food security and step up efforts to deal with idle land and use every inch of land economically.
4	Strengthen efforts to control pollution in order to improve the quality of ecological environments.	Firm action to control air pollution; significant efforts to address water and soil pollution; practical steps to protect ecosystems; mount an active response to climate change.	All local governments and departments are required to conscientiously implement major decisions of the central Government; revert farmland back to forest and grazing land to natural grasslands; lower CO_2 emissions by 40-45% by 2020 (compared to 2005 level); increase proportion of non-fossil fuel energy in primary energy consumption by 15%; increase forest area coverage by 40 million hectares and forest volume by 1.3 billion cubic meters relative to 2005 coverage and volume, respectively.
5	Improving laws and regulations and creating innovative systems and mechanisms to underpin ecological progress.	Strengthen existing laws and regulations to promote ecological progress; systems to assess and appraise current modes of economic development; further improvements to market mechanisms and economic policies.	Establishment of an ecological civilization requires revolutionizing the way the country produces, lives, thinks and the values it cherishes; institutional arrangements and reform of administrative systems as a means to protecting ecological environments; life-long accountability system for ecological damage for leading cadres; polluter pays and trans-ecological compensation system; systems for trading energy savings, carbon emission rights, pollutant discharge rights and water usage rights.
6	Green and low-carbon consumption in order to create a sound social atmosphere for ecological progress.	Accelerate efforts to raise awareness of ecological progress; advocate green life-styles; make effective use of public oversight.	Ingrain the notion of ecological progress deeply within the conscience and actions of the public; establish ecological progress as mainstream value and spread it to all corners in all respects; and develop a moderately prosperous society in all respects.

our knowledge, no one has explicitly advocated for a fifth, political pillar of sustainable development. But calls for improved environmental governance and for innovations on institutional arrangements for sustainable development implicate national and local politics as important drivers of change.

In opting for "ecological" (instead of "environmental") as an adjective for "progress" and "civilization", Chinese leaders have chosen to emphasize analytical, system-based thinking and action. Changes that China must undergo to execute inter-linked, multi-sectoral and system-wide changes described in Table 1 require knowledge and wisdom as well as long-term commitment to action, experimentation and learning. Hardin [12] believed that what engineers called “system analysis” and biologists referred to as “ecology” were similar approaches to understanding and knowledge development. In the five-pronged approach (i.e., cultural, ecological, economic, political and social) to build an ecological civilization the rates of change Chinese planners and administrators can influence in each of the five domains will vary over space and time. Relative stability in cultural and political domains can facilitate accelerated rates of changes in ecological, economic and social spheres. Within the vast landmass that is China the specific mix of the five prongs in particular places and over given periods of time will create a patchwork of regions and localities that are advancing at varying rates towards the goal of ecological civilization. Norgaard [13], in his reflections on the discourse on ecological civilization initiated by China imagined it to be a “patchwork quilt of co-evolving ecological societies”. Earlier on Ref. [14] he had introduced co-evolution as a central concept in re-visioning future societies.

3. Glimpses into the Emergence of an Ecological Civilization in Practice

China’s appetite for fish and its impact on global fish-stocks are frequent causes for alarm among environmentalists. But the efforts of some Chinese scientists and business-people to reinvent China’s aquaculture [15] are perhaps less known. They have adopted IMTA (Integrated Multi-Trophic Aquaculture), tested in Canada, Scotland, US and Norway and scaled it up to create “ocean ranches” as well as 18,400 sq.km of fishponds, that in the words of a reputed Norwegian fisheries expert is “a completely different thing than what we are doing.” IMTA transfers the logic of circular economy to fisheries ecology: multiple species recycle each other’s excrements (or nutrients). IMTA in Canada’s Bay of Fundy is a series of neighboring cages with nutrients flowing down-current with water. The Chinese version in Zhangzi and neighboring Islands has transformed islands into *in-situ* cages; while Fundy produces 200 tons of kelp and 300-400 tons of mussels per year, islands around Zhangzi produce 60,000 tons of kelp, 200 tons of sea-urchins, 300 tons of oysters, 700 tons of sea-snails, 2,000 tons of abalones and 50,000 tons of scallops each year.

Vance’s [15] description of the on-going revolution in China’s aquaculture is a clear illustration of the application of ecological knowledge to address and solve interlinked problems of the environment, food security and economic growth. The emphasis is clearly on learning through doing, i.e., practice. The effort is based on an intimate study, knowledge and tinkering of ocean currents and water flows and their modeling to simulate flow of nutrients. Artificial reefs are built and sustained to recover ecosystem health in coastal areas. Scientists from the CAS (Chinese Academy of Sciences) collaborate with fish businesses and fish farmers to experiment in particular contexts in order to generate tangible benefits for the stakeholders concerned. Vance [15] quotes the same Norwegian fisheries expert referred to earlier on with regard to the Chinese approach: “They are mastering these challenges. Not to perfection—no way—but much better than anywhere else.”

Practical experimentation on terrestrial ecosystems is equally critical. While only 12% of China’s 9,560,900 km^2 (1,147,308 km^2) is arable, China has committed to sustain 1,200,000 sq.km of agricultural land to ensure food security and the efficient use of every inch of land (see facts and issues linked to principle 3 in Table 1). At the same time the country has ambitions to revert farmland back to forest (see fact and issues linked to principle 4 in Table 1). In China a majority of initiatives for reducing carbon emissions are concentrated in industrial and energy sectors; the 7 pilots for experimentation with ETS (Emission Trading Schemes) are almost entirely dedicated to these sectors in 5 cities and 2 economically prosperous provinces in the east of China [16]. But a mix of improved agricultural practices, afforestation/reforestation and rural energy efficiency and development options have the potential to contribute not only to food production and security goals; but also to reducing ammonia and nitrous oxide linked emissions by 10%, lower CO_2 emissions by 40-45% by 2020, and create "10,000 Enterprises Energy Efficiency and Low Carbon Program" (see facts and issues of principles 3 and 4 in Table 1).

In China's Shanxi Province, 50% reduction in fertilizer use has been linked to 4%-15% increase in farmer household incomes [17, 18]. China is a world leader in biochar research [19]; biochar has proven potential for minimizing green house gas emissions by decreasing the need for nitrogen based fertilizers. Each unit of nitrous oxide emission is nearly 300 units of CO_2 emissions. Biochar is known to increase crop-yields by several folds particularly in arid and semi-arid soils that dominate China's Western Provinces. It has the capability to improve quality of poor and degraded soils. Manufacture of biochar can be accompanied by syngas and biofuels for use in rural energy and transport and for stimulating rural enterprise and employment opportunities [20]. China recently issued a ban on straw burning, a major source of green house gas emissions in the agricultural sector. The ban has stimulated small businesses for the collection of farm residues at the local level and their delivery to factories that produce a mix of biofuels, biochar and bioenergy for rural development. The Nanjing Agricultural University and its industrial and business partners have cooperated in the production of a number of biochar based fertilizers that are now available in the market. However, their wider use and application requires raising awareness of local authorities and farmers with regard to the mix of ecological, social and economic benefits that the use of biochar products can generate [21].

If China is to sustain a minimum of 1,200,000 km^2 of land for ensuring food security and at the same time be able to revert farmlands to forest and natural grasslands (facts and issues linked to principle 4 in Table 1), then it not only must strive to "use every inch of land economically" (see facts and issues linked to principle 3 in Table 1). It should launch programs to recover land degraded by mining and other industrial operations and find ways of improving productivity of marginal lands where soil quality is poor. Biochar and other green agricultural technologies and tools have a significant potential to contribute towards the development of green and low-carbon agriculture as part of China's ecological civilization experiment.

Since 2000, China's NFPP (National Forest Protection Program) and SLCP (Sloping Land Conversion Program) have increased China's forest cover by more than 60 million hectares making China one of the world's leading nations implementing afforestation schemes [22, 23]. It is rather ironical that carbon credits generated through such a massive rehabilitation program could not be part of emission trading schemes that developed under the Kyoto Protocol and came into effect after 2005. Kyoto linked emission trading schemes, focusing almost entirely on energy, industrial and power sectors have ignored the potential for bringing land use change into carbon equations and for linking industrial and land use sectors in innovative ways to encourage simultaneous emission reduction and carbon sequestration actions. A critic of the Kyoto Protocol, Victor [24] observed that "the more credit awarded for CO_2 that plants and trees are already absorbing, it is easier for nations to comply with Kyoto targets…," China's vision for an ecological civilization must extend beyond its international obligations for mitigating and adapting to climate change. It can create opportunities to interlink emission reduction targets in the industrial and power sectors to land use change based carbon sequestration schemes and restoration of natural and agricultural ecosystems.

Globally, the potential for trading carbon credits generated by land use changes has improved in recent years with greater recognition of the importance of IFM (integrated forest management) and SALM (sustainable agricultural land management) for mitigating climate change [20, 25]. Chandler Van Voorhis, managing partner of "Green Trees" reported a study which showed that "if reforestation/afforestation is scaled to its maximum across the globe, we can sequester 5.5 billion tons of CO_2 globally a year, which is about 15% of the reductions that we need. By 2100 this would reduce the temperature curve by 10% or by 0.2 °C". He further adds: "…a tree has no economic value until it is cut down…What happened when carbon came along is it started to have some economic value. When you start adding other ecosystem values like water and biodiversity, you start creating a capital stack" [26]. Environmental (biodiversity, water, soils), social (job-creation, building schools, hospitals and other infrastructure in rural and remote areas) and economic (increased revenue generation; attracting private sector investment interests) co-benefits are sought after by project developers who focus on land-based emission reduction schemes because a "carbon reduction is relatively intangible" [27] for ordinary citizens to perceive or appreciate.

Land use change based carbon emission reductions have become a significant component of voluntary carbon markets worldwide and co-benefits are given significant importance by investors and offset-buyers who are engaged with such markets [28]. As the infrastructure for carbon markets begins to take shape in China, it is worth considering a greater role for voluntary market transactions that can generate multiple ecosystem benefits across the nation. Currently the trial Beijing Emissions Offset Management Measures for carbon-intensive entities allows the use of CCERs (China Certified Emission Reductions) to offset only 5% of their total allowance [16]. However, as Gaoli [6] has noted (see facts and issues linked to principle 5 in Table 1): "Establishment of an ecological civilization requires revolutionizing the way the country produces, lives, thinks and the values it cherishes; institutional arrangements and reform of administrative systems as a means to protecting ecological environments; life-long accountability system for ecological damage for leading cadres; polluter pays and trans-ecological compensation system; systems for trading energy savings, carbon emission rights, pollutant discharge rights and water usage rights." Trans-ecological compensation systems may link developed and developing regions as well as spatially distant urban, rural and the natural ecosystems within the country through a mix of market and public sector institutional arrangements. And if emerging trading schemes are to encourage stacking together energy savings and carbon emission rights with other benefits linked to clean water, biodiversity, soil productivity and other ecosystem benefits then China may learn as much or more from the global voluntary carbon markets compared to what it can based on its experience with the Kyoto Protocol which has suffered significant set-backs in the international arena since 2009. As China embarks upon decades, if not even centuries-long, experiment to build an ecological civilization it must be creative in adapting lessons learnt from the implementation of international conventions and protocols. It can create institutional arrangements and linkages between different development sectors that can take full advantage of its own cultural strengths and governance system.

4. Ecological Civilization Area—A Network of Places for Experimentation and Learning

The eco-civilization experiment in China cuts across all sectors and regions. China's leadership in some aspects of renewable energy, the determined shift away from coal to natural gas to supply electricity to major cities like Beijing are essential parts of that continuing experiment. However, as noted by Kai [4] quoted earlier, in the Chinese leaders understanding ecological civilization refers to the "level of harmony that exists between human progress and natural existence in human civilization." Hence, places in China where opportunities for bringing the interests of human and nature together to demonstrate harmonious way of growth and development must play an important role in promoting ecological progress in China.

Nationally, 15% of China's surface area is set aside as nature reserves, scenic areas and forest parks [29]. Like in many other parts of the world, areas set aside for nature conservation are much larger in sparsely populated and low (agriculturally) productive regions; according to Ref. [30], eight large reserves in the five western provinces cover an area that is roughly equal to 2,000 of the remaining 2,500 parks and reserves in other parts of China. CBRN (Fig. 1) includes more than 150 of these sites; 32 of them are part of the World Network of Biosphere Reserves of UNESCO.

The origin and the evolution of the concept and practice of biosphere reserves have been analyzed elsewhere [31, 32]. Designated under UNESCO's Man and the Biosphere (MAB) Program, biosphere reserves have an explicit goal of promoting a harmonious relationship between humans and nature. Conventional national park models use legal definitions, boundaries and tools to protect and conserve nature. But biosphere reserves, despite the fact that all of them include one or more legally protected core zones where nature and biodiversity conservation are the primary concerns, also include buffer and transition zones where people live, agriculture, forestry and other economic sector activities are practiced and at times even include urban areas. The presence of resident communities and human enterprise is a necessary condition for biosphere reserve status; a strictly protected nature reserve with no people residing in it will not qualify as a biosphere reserve. As such they bring together the two essential components, i.e., people and nature, of the ecological civilization imagination in China. Furthermore, coordination of Chinese Biosphere Reserve activities are directly under the CAS (Chinese Academy of Sciences) facilitating collaboration between scientists, administrators and resident communities that is critical to the building of an ecological civilization.

In some biosphere reserves of China, authorities have succeeded in improving economic and social benefits arising from tourism management and their distribution among local villages and communities. In the 106,000 ha, Jiuzhaigou Valley Biosphere Reserve (JVBR) in Sichuan Province, which includes the 72,000 ha, Jiuzhaigou Valley Scenic Area and World Heritage site, authorities introduced drastic measures to minimize negative environmental and social impacts when the number of visitors to the area grew by 68% between 1998 and 2000. Hotels inside the core zone of the reserve were shut down and construction of new hotels halted; a joint stock company where residents were shareholders was created to take away incentives for uncoordinated construction of new hotels and for providing employment opportunities for those whose livelihoods were adversely impacted due to the changes introduced. Entering the reserve in private vehicles was banned and the administration operated buses for taking groups of visitors into the reserve. Income distribution among three villages studied changed from 4.3:4.6:1.0 during 1993 to 2001 to 1.9:2.5:1.0 in 2004 [33].

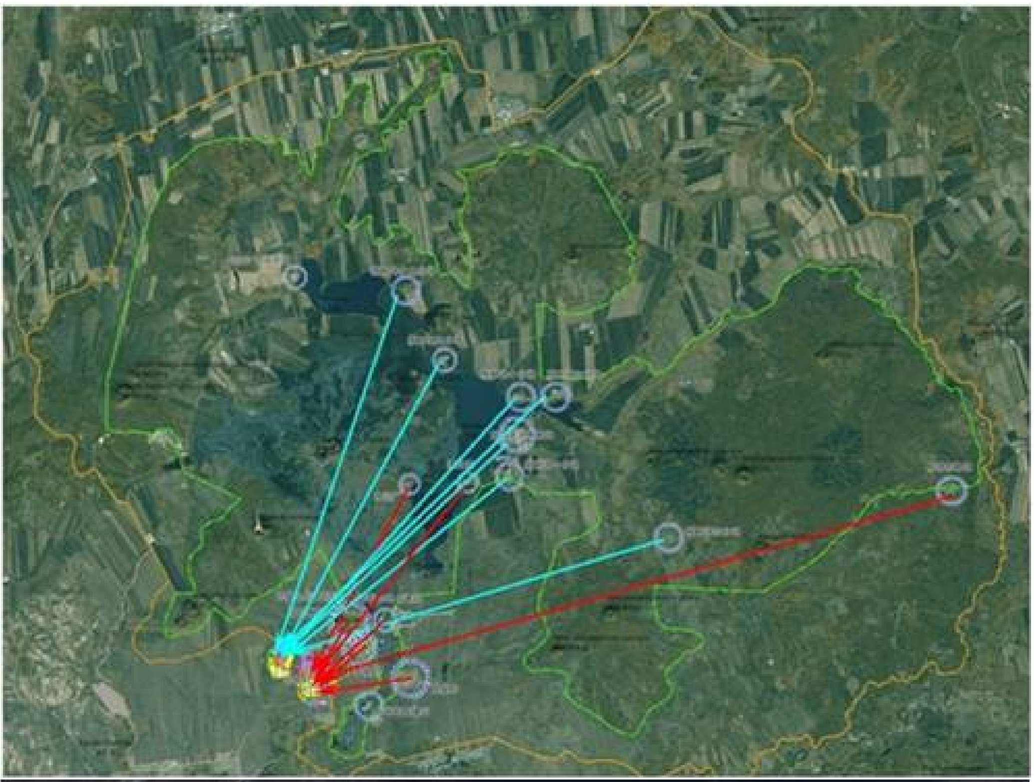
Harris [30] and Yeh [34] have observed that in many Chinese nature reserves communities tend to be resident even within the core zones. Relocating people from within the core zone is a task that requires careful planning and constant negotiations between administrators and resident communities. The administration in the Wudalianchi Biosphere Reserve in Heilongjiang Province in the northern extreme of China used a process of consultation and engagement to resettle residents from the core and buffer zones to a new "eco-city" developed to promote tourism in the biosphere reserve. People were relocated to an area where infrastructure for schooling, health, sports and recreational activities were developed and which could never have been made available to them within the core zone (Fig. 2). For the future, the Wudalianchi administration has identified "green agriculture" in buffer and transition zones as a socially and ecologically beneficial land use option that could help to diversify income generation and wealth creation opportunities from a singular dependence on tourism that is characteristic of many parks and reserves throughout the world.

In the construction of an ecological civilization China's leaders expect to introduce administrative reforms that will hold leading cadres responsible for ecological performance throughout their working life (see fact and issues related to principle 5 in Table 1). At the same time, as underlined in facts and issues linked to principle 6 in Table 1, ecological progress is to be ingrained as a mainstream value within the conscience and actions of the public at all levels in all respects. Hence, the process of the construction of an ecological civilization must engage planners and administrators as well as citizens. Opportunities for deliberative planning and learning through civic action and engagement of planners and the public in joint definition of problems and their solutions [35] must be created and promoted. Biosphere reserves, with their essential mix of people and nature provide the best laboratories for experimenting with such collaborative planning, action and engagement for learning lessons and sharing them within China and internationally. They can become the "patchwork quilt of ecological societies" within China, as imagined by Norgaard [13] referred to previously; and at the same time raise awareness and stimulate other "patches" to emulate, experiment, learn and join the progress towards an ecological civilization.

However, planning as well as other design professions that impact public spaces and people is "deeply and inevitably political" [35]. Chinese planning and governance model, which appears centralized and top-down to external observers nevertheless can and does encourage considerable negotiations and deliberations amongst context-specific stakeholders at the local level. Since deliberations occur in the Chinese language, outsiders without the language proficiency who would like to learn from specific cases in China require considerable patience and commitment to stay engaged.

International engagement with China and its efforts to build an ecological civilization must be based on an acknowledgement and respect for China's cultural and political specificities and reasonable expectations. In the nature conservation arena, claims that the national park presented a "new model" of conservation [34] through the establishment of China's first national park (Pudacuo National Parks in northwest Yunan) for using market based methods to combine conservation and community benefits through tourism revenues have been disappointing. In our view they were not needed given the fact that experience in doing so have already been gained in places like JVBR referred to earlier. The national park model started with Yellowstone in the United States in 1872 and is about to commemorate 150 years of practice in 2022 and does not qualify as a new approach. Until about the early 1970s application of the national park model prevented local people access to resources with main uses of the area being scientific, educational and recreation and leisure for those who visited the parks. The biosphere reserve approach was introduced in the early 1970s partly as an alternative to the national park model in practice at that time; biosphere reserves, from very early days, explicitly prioritized the need to recognize and cater to the interests of local communities [31, 36].

Assumptions about introducing market based methods that ignore the reality of the dependence of local Governments and administrations of China's nature reserves and scenic areas on tourism and the



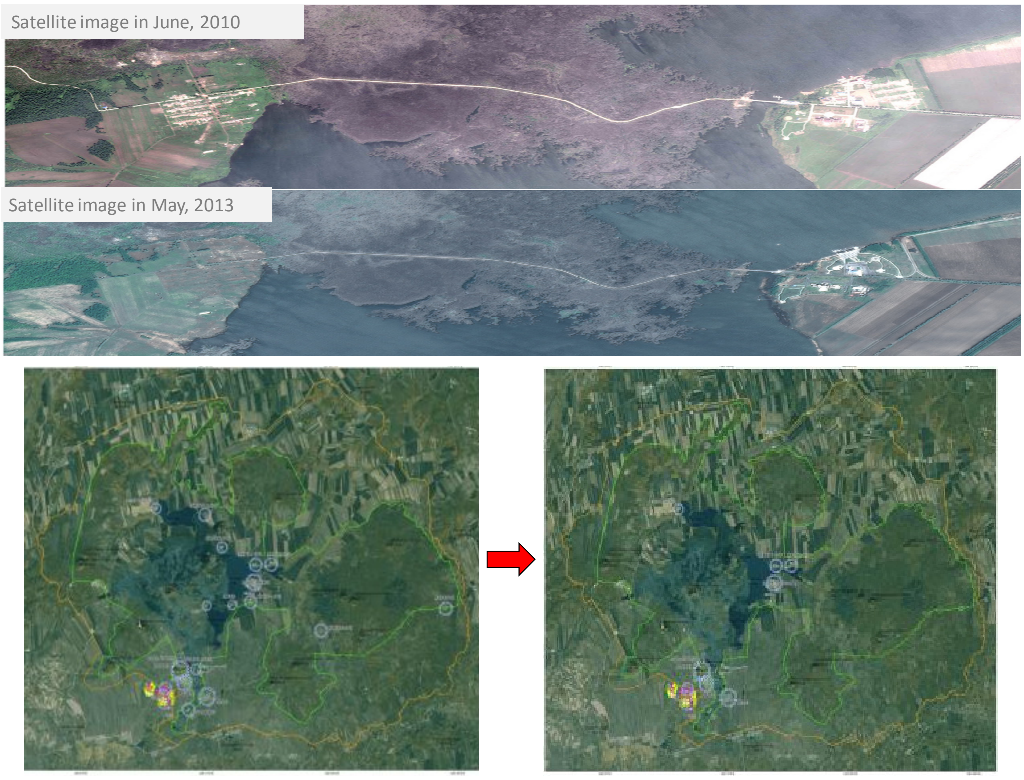


Fig. 2 Three images for illustrating the movement of people from within the Wudalianchi Biosphere Reserve to the new eco-city (image one showing arrows of movement). Image 1 shows the directions of movement of people from within the Biosphere Reserve towards the eco-city. Image 2 shows a model of the new eco-city built to house the people who moved away from core and buffer zones of the Reserve. Image 3 shows improvements in the ecology of the areas vacated by people as shown by satellite images obtained for 2010 and 2013.

hospitality sector for income generation fail the test of pragmatism. As Yeh [34] has observed implementation of several payment-for-ecosystem services (PES) schemes in developing countries, including China's SLCP scheme referred to earlier in this paper do not satisfy free-market model assumptions and continue to be hybrid-schemes combining public and private sector financing and inputs. Pirard and Lapeyre [37] analyzed a sample of 106 peer-reviewed articles and questioned the validity of the widespread use of the term, Market Based Instruments (MBIs), since in practice most cases had strong public sector financing and in-kind contributions. The drive towards an ecological civilization will be one where public and the private sectors and Government and market instruments are innovatively mixed to deliver desired results within the constraints and opportunities offered by China's specific cultural and political characteristics. As Forester [35] has wisely observed, "Astute practice in messy, highly politicized settings provides important intellectual challenges to planning theory, and to social and political theory more generally. Tacit practice can lead written theory." It is important that in the efforts to build an ecological civilization, cultural and political realities on the ground must be duly acknowledged as such and measures introduced to drive economic, social and ecological change in a balanced and preferred direction. Too much reliance on purely theoretical approaches is bound to disappoint.

Last but not the least, the use of biosphere reserves that combine conservation and socio-economic growth and expansion in different zones allows Chinese planners and managers to develop applied knowledge and experience for "optimizing spatial planning on the basis of functional zones" (see principle 1 in Table 1). At the national level discussions on functional zones tend to focus on the urban-rural divide. But at the level of a specific place such as the Wudalianchi Biosphere Reserve, spatial planning, benefiting from space, air and ground based sensing technologies and other advanced science and technology practices can enable and facilitate participatory planning and learning by both administrators and citizens for jointly defining the distribution of ecologically, economically, socially and culturally important land use patches within their own space of life and work. The creation of special ecological civilization areas in some biosphere reserves that are part of CBRN will help make the learning linked to addressing and resolving the intellectual and practical challenges of building an ecological civilization more systematic and shared.

5. Conclusions

Fang and Kiang [38] noted that "China's extraordinary rate of economic development makes it a historically unique grand scale socio-economic and ecological experiment. No one knows what the future holds, but there is no doubt that the experiment will have an unprecedented impact not only on the country's own environment and that of its neighbors but on the world as a whole." Nearly six years after this observation was made by two of China's leading ecologists the Government of China declared its commitment to build an ecological civilization. The commitment has significantly expanded the world's interest on China's pragmatic and experimental approach to development and future.

Deutscher [39], a linguist, observed that "English speakers rely on their language as a fallback strategy when they are required to solve a vague task for which there does not seem to be a clear answer." The future of our earthly home, in the light of our growing awareness of the ills we have, and continue to impose on climate and nature, is a question for which we now have only vague answers. It is not surprising that "sustainable development" has often been criticized as an oxymoron even though it has become a rallying vision for the nations of the world to collectively discuss remedies for the earth's environmental problems and the search for new directions of socio-economic development [40]. Ecological civilization as an idea gives expression to the commitment of China to seek alternative development pathways that will benefit its own and the world's ecology. Contributing towards its realization is a challenging and worthy venture.

However, intellectual clarifications of the notion of ecological civilization alone will not ensure that the dream becomes a reality. The task requires experimentation in real-life circumstances engaging scientists, planners and administrators and citizens and the public to come together and share knowledge, experience and learning. Scientific research must engage with the messy, disorderly reality of the world and grasp opportunities for other actors in society to become collaborators and data providers. Encouraging the practice of such "science in the wild" [41] would require changes in reward and incentive schemes currently offered to Chinese scientists.

The dawn of ecological civilization over a vast land mass such as in China will inevitably be patchy. But experimentation, learning, sharing and emulation can be encouraged by promoting and incentivizing legal, regulatory and administrative changes in dedicated areas for facilitating the transformation towards an ecological civilization. We have proposed that the places included in CBRN could provide candidates for establishing such dedicated ecological civilization areas, paralleling free trade and similar zones that have been set up for China's rapid economic growth over the last three decades. Continuous experimentation to create conditions for the emergence of an ecological civilization in context-specific, local geographies will also enable citizens and public to engage in the national agenda and better understand the meaning and implications of changes needed for themselves now and in the future. In building an ecological civilization it is hence important to not merely "think ourselves into a new way of acting" but also "act ourselves into a new way of thinking" [42].

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Soil Microbial Activity and Functional Diversity in Primeval Beech Forests

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Abstract: Virgin forests are unique ecosystems, which can be used as etalon for basic biocoenotic investigation. Soil microorganisms are very sensitive reagents on influence of biotical factors, and at the same time are the active producers of phytotoxic and phytostimulating exometabolites. Studies of soil microbiota were conducted in virgin beech forests of Shyrokoluzhansky massif of the Carpathian Biosphere Reserve. It was found the ratio and the number of different ecological-trophic groups of soil microorganisms changes with altitude. So the number of ammonificators with increasing of altitude above sea level was reduced. The soil at altitude of 1,100 meters above sea level was characterized by minimum content of organotrophes -1.22 × 10^6 (CFU-colony forming units/1g.a.d.s.). At the altitude of 500 meters content of ammonificators increased at six times and was 7.07 × 10^6 CFU/1g.a.d.s., which indicates to accumulation of the soil organic matter. Similar changes occurred with the number of bacteria which are using mineral forms of nitrogen for their nutrition. Their maximum quantity (4.32 × 10^6 CFU/1g.a.d.s.) was in the soil of biotope disposed at altitude of 500 meters above sea level. Fluctuations in the number of soil micromycetes of virgin forest ecosystems have not been as significant as the bacterial microbiota (within 17 × 10^3-28 × 10^3 CFU/1g.a.d.s.). Among a wide spectrum of bacterial microbiota were isolated strains with high phytostimulating action.

Key words: Soil microorganisms, primeval beech forests, biological activity of soil, phytotoxicity of soil, biocoenotic activity of microorganisms.

1. Introduction

A primeval beech forests are the biogeocoenoses which were created during phylocoenogenesis in corresponding to soil-climatic conditions and landscapes. Autotrophic and heterotrophic elements of primeval forest ecosystems and pedosphere have no indications of such antropogenic influence which could change their natural status and sylvagenesis. Hence they function as homeostasis ecosystems [1]. As etalon ecosystems, they better combine above resistance and stability with high productivity biomass. Therefore the virgin forests reliably indicate the direction of restoration of disturbed ecosystems [2, 3]. Virgin forests are essential for the conservation of biological and genetic diversity. They reserve the relict and endemic species of flora and fauna. The study of primeval forest is a unique opportunity to explore the natural structure, diversity and genetic structure of unmodified forest and ecosystem dynamical processes and relationships that occur in them under the influence of ecological factors. Despite of the intensive exploitation of forests in the last ten centuries, its area decreased by 3.5 times, and virgin forest ecosystems which have special value remained only in the Carpathian Mountains. Moreover, since most European forest stands have been managed for centuries [4], very little is known about the diversity, ecology, and distribution of soil microorganisms in natural, undisturbed forest ecosystems in Europe. The few remnants of natural forests which could be potentially investigated, are not larger than 50-100 ha, while continuous forest areas of more than 1,000 ha are very rare. In the Transcarpathian region of Ukraine

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(south-west), the CBR (Carpathian Biosphere Reserve) offers a unique opportunity for studying the biodiversity and natural processes of virgin or primeval forest ecosystems, i.e. forests that have never been significantly modified by human activity. The region covers an area of about 53,650 ha and became part of the World Network of Biospheres Reserves of UNESCO in 1992. However, it should be noted that the attention of researchers focused mainly on studies of flora and fauna biodiversity [5, 6] and almost never directed to the ecological study of soil microbial communities. Microbial communities degrade most of the organic material that settled on the forest soils. The organic matter decomposition rate depends on physical factors, substrate quality and the type of microbial community. The degradation of certain compounds by specific bacteria, leads to succession of microbial community until all the substrate is completely decomposed [7]. Some saprophytic fungi and bacteria, are the primary agents that induce decomposition by the degradation of organic compounds as: cellulose, hemicellulose, pectin and lignin [8]. Bacteria have an important role in the nutrient cycling. The distribution of bacteria in forest soils is mostly determined by vegetation and soil chemical characteristics. For example, the study conducted by E. Hackl, compared the bacterial communities of six forests under different pine and oak vegetation. The results showed that Gram-positive bacteria communities, especially actinomycetes, were more abundant under conifer forests than under oak coverage. These results suggest that bacterial communities are adaptive to the soil chemistry. Due to this fact, the purpose of the research was to determine the number of different ecological-trophic groups of soil microorganisms, biological activity and phytotoxicity of soil, intensity of microbiological processes by index of pedotrophity, oligotrophity and isolation of microbial strains with phytostimulating action.

2. Materials and Methods

Samples of soil for study were taken in the virgin forests of Shyrokoluzhansky massif of the Carpathian Biosphere Reserve, Ukraine. The total area of the massif is about 15,033 ha [8]. The massif consists of two contiguous areas (foresteres): Uholka and Shyrokyi Lug. It lies within the Krasnyanskyi physical-geographic area of the Middle maountain-Polonyny region and Uholka physical-geographic area of the Low mountain-Rocky region. It is located between the rivers Tereblya and Teresva. The massif is separated by the mountain range Krasna from the Mokryanka river valley and lies within the Duklyanska, Prokuletska, Rakhiv and Maramorosh tectonic zones. The Duklyanska zone covers the northeastern part of the massif and is represented by sandy and clay-sandy flysch. The southwestern part of the massif is occupied with the formations of the Prokuletska zone, which is represented by massive diverse-grained sandstones. The southern part of the massif is made up of the Maramorosh rocky zone sediments, which are represented by Cretaceous sediments, Palaeogene sandstones, gridstones, aleurolites, marlstones and argillites, and also small-grained greenish-grey flysch with some stratums of grey small-grained sandstones. The soils are very stony, mostly midloamy with good water and air penetration ability [9]. Climate conditions change from mild-warm to cold. The massif belongs to three different climatic zones with annual average temperatures ranging from 0 to +7 °C and annual average precipitation varying between 1,000 mm and 1,500 mm. The temperature in July elevates from +17 °C to +12 °C, and in January from -3 °C to -10 °C. The sum of active temperatures changes with the altitude from 2,300 °C to 800 °C. Researches were conducted from 2008 to 2014 years. Sampling was carried out by squares method in depth of 0-25 cm at different altitudes from 500 m to 1,100 m (Table 1).

Table 1 Characteristics of the soil sampling location in virgin beech forests.

No.	Vegetation	Coordinates (latitude; longitude)	Altitude above sea level, m
1	*Fagetum (silvaticae)*	48°18.671′; 23°44.388′	500
2	*Fagetum (silvaticae)*	48°21.087′; 23°43.398′	600
3	*Fagetum (silvaticae)*	48°18.450′; 23°43.227′	700
4	*Fagetum (silvaticae)*	48°19.928′; 23°42.879′	800
5	*Fagetum (silvaticae)*	48°21.562′; 23°43.425′	900
6	*Fagetum (silvaticae)*	48°19.344′; 23°45.620′	1,000
7	*Fagetum (silvaticae)*	48°21.810′; 23°44.532′	1,100

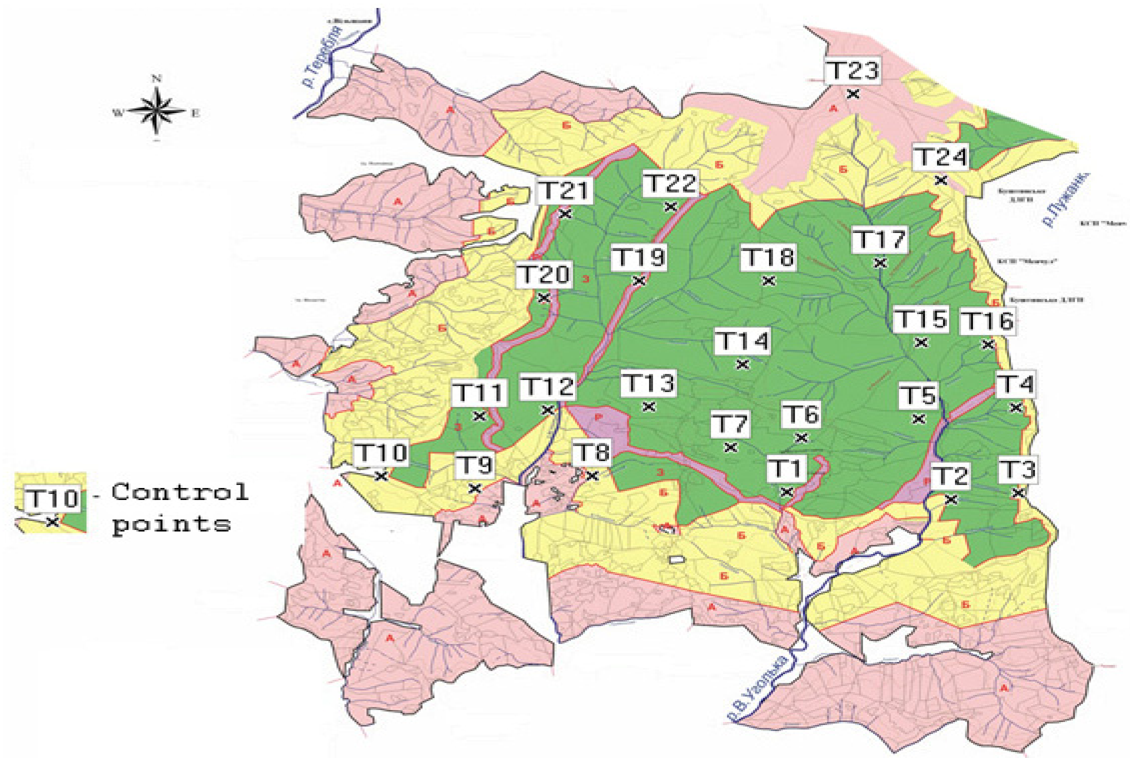

Fig. 1 Map of the soil sampling in virgin beech forests.

Microbiological analysis of soil has been carried by standard methods [9-11].

Samples of soil were collected in a sterile container from all investigated plots (Fig. 1).

The biological activity of the soil was determined by Kazeev et al. [12], direction of microbiological processes in the soil by K. Andreyuk and methods described by Volkohon [13, 14].

Mineralization - immobilization calculated by the formula:

$K_{m\text{-}i} = C_{KAA}/C_{MPA}$, where C_{KAA}, C_{MPA}, the number of microorganisms that grew on ammonia agar and meat peptonic agar.

Oligotrophity of soil using the formula:

$K_{ol} = C_{PA}/(C_{KAA} + C_{MPA})$, where C_{PA}, the number of microorganisms grown on pure agar.

Pedotrophity of soil:

$K_{ped} = C_{S.A}/C_{MPA}$, where $C_{S.A}$, the number of microorganisms grown on soil agar.

Toxicity of soil samples was determined by the Berestetsky method [15]. The dominant bacteria colonies were isolated by morphological characteristics: colour of colonies, size (10 mm or more—large, from 1-10 mm—average less than 1 mm-point), the edges of the colony, its texture and isolated in pure culture [16, 17] Bacteria belonging to different genera and species were determined by Bergey [18]. It is established [19-22] that the stimulating effect of microorganisms on plant appears after seed germination. On this established method for detecting microbial stimulants. Enrichment of microbial metabolites is carried out by soaking the seeds in the culture fluid of the studied strains. Broth diluted with water is used for soaking seed culture. Dilution 1:50—is used at the initial selection of microbial stimulants. Dilution 1:100 is used for a more detailed study of the active strains; 1:200, 1:500 to determine the optimal concentration at which the maximum stimulating effect detected. Radish seeds were used as a biotest. Weight seedling roots, dried at 60 °C to constant weight were used as the test characteristics. The SE (stimulating effect) expressed in percentage (%) and was determined by the formula:

$SE = (M_{r1}/ M_{r2}) \times 100\%-100$

M_{r1}: weight of roots while processing of culture fluid;

M_{r2}: control weight of roots.

Statistical analyses were conducted using software Statistica 7.0.

3. Results and Discussion

There are preserved virgin ecosystems of particular value in the Carpathian Biosphere Reserve. The beech forest's soil microbiota studies are very important, they are sensible reagents to the impact of external factors, ecosystem indicators and succession processes that occur in them [23-25]. We have established that the number of different ecological-trophic groups of soil microorganisms varies with the height of the habitat above sea level. The number of amonificators with increasing height decreased, minimum content organotrophies 1.22 (colony forming units per 1gr. absolutely dry soil) was characterized soil at altitude of 1,100 meters above sea level (Table 2).

As shown in Table 2, at the altitude of 500 meters content of ammonificators was at six times higher and amounted to 7.07 million CFU/gr.ab.d.s., what indicating a significant enrichment of soil organic matter of plant origin. The similar changes in the bacteria content, in the case of bacteria that used mineral nitrogen were observed. The maximum number of these microorganisms—4.32 million CFU/gr.ab.d.s. was in the soil at the altitude of 500 meters above sea level.

At the highest point of sampling (1,100 m.) their number was 2.82 times lower. Fluctuations of number micromycetes were not as significant as bacterial flora, but in edaphotops located within 500-800 meters their biodiversity was higher than at other sampling points.

The content of microscopic fungi in the soil of virgin ecosystems was 17-28 thousand CFU/gr.ab.d.s. The number of oligotrophic and pedotrophic microbiota with increasing altitude increased, indicating a decrease in nutrients necessary for life of the soil microbiocoenosis (Table 2). In order to assess

Table 2 Number of different ecological-trophic groups of soil microorganisms in the virgin beech forests.

No.	Altitude above sea level, m	(CFU-colony forming units/ per 1 gram of absolutely dry soil)					%
		Micromycetes, $\times 10^3$	Ammonificators, $\times 10^6$	Oligotrophes $\times 10^6$	Pedotrophes $\times 10^6$	Bacteria which are using mineral forms of nitrogen $\times 10^6$	Azotobacter
1	500	17	7.07	2.33	1.68	4.32	80.23
2	600	20	4.30	2.61	1.88	3.64	68.44
3	700	20	3.46	2.87	2.00	3.22	60.29
4	800	21	2.93	3.24	2.26	3.14	58.56
5	900	25	1.66	3.70	2.96	2.18	54.67
6	1,000	26	1.30	3.80	3.12	1.96	50.13
7	1,100	28	1.22	3.94	3.65	1.83	41.34
SSD_{05}	-	0.32	0.14	0.41	0.18	0.21	1.28

SSD_{05} - smallest significant difference.

Table 3 Direction of microbiological processes on soil in primeval beech forest.

No.	Altitude above sea level, m	Coefficient of oligotrophity	Coefficient of pedotrophity	Coefficient of mineralization-immobilization
1	500	0.20	0.23	0.60
2	600	0.31	0.44	0.84
3	700	0.37	0.57	0.93
4	800	0.50	0.77	1.07
5	900	0.94	1.80	1.31
6	1,000	1.18	2.40	1.50
7	1,100	1.29	3.00	1.50

the direction of microbiological processes in the soil of beech forests the calculation of coefficients of oligotrophity, pedotrophity and mineralization-immobilization were carried out (Table 3).

As can be seen from Table 3, the coefficients of oligotrophity and pedotrophity of soil increased with the altitude and their maximum value were at the height of 1,100 meters respectively 1.29 and 3.00. Increasing of the pedotrophity indicates an intensity of decomposition of a soil organic matter, including humus substances. The increasing of the oligotrophity of the soil indicates the reduction of nutrients in the soil. Minimum of these coefficients were at the altitude of 500 meters above sea level: the oligotrophity coefficient -0.20; coefficient of the pedotrophity -0.23 that of 6.4 times and 13 times less than the maximum values of these parameters in the studied ecosystem. Intensity of mineralization processes in the soil also increased in proportion to height of the investigation edaphotopes and maximum values reached at 1,100 m, the rate of mineralization-immobilization was 1.50 which is 2.5 times higher than in edaphotopes at altitude of 500 m. Succession, dynamic changes of microbial communities of soil related primarily from the impact of biocoenosis abiotic factors such as temperature and humidity.

Rebuilding the functional structure of soil microbial coenosis due to the influence of exogenous factors, as evidenced not only by changing the number of specific ecological-trophic groups of soil microorganisms [26], but also from direction of microbiological processes in soil of virgin ecosystems.

Toxic substances produced by microorganisms enter the plant directly from the soil, and they are concentrated mainly in the overground organs, and almost not observed in the roots of plants. Phytotoxines of soil microorganisms cause significant changes in the chemical composition of plant metabolism to break them (impact on nitrogen and carbohydrate metabolism), inhibit seeds germination, growth of sprouts, plant growth and reduce harvest [27, 28]. Toxic forms of microorganisms found in all types of soil.

The genera *Bacillus* and *Pseudomonas* are more often among the bacteria; among micromycetes—*Penicillium, Fusarium*; among streptomycetes—*Streptomyces aurantiacus, S. viridans, S. griseus* [29, 30].

Phytotoxines that formed by soil microorganisms belong to different groups of chemical compounds. There are nitrogen-containing and oxygen-containing heterocyclic compounds and aromatic substances acyclic structure, derivatives of phenols, quinones, and terpenoids among them [31]. More important toxic activity of strains and their inhibitory ability, than in the soil they accumulate in large quantities [32, 33]. Soil in virgin forest ecosystems, characterized by relatively low levels of phytotoxic activity: 14%-21% (Fig. 2). In contrast, anthropogenically transformed ecosystems characterized by very high levels of phytotoxic activity on average three times higher than background levels.

The maximum level of phytotoxical activity (21%) was characterized by samples of soil taken at height of 1,100 meters above sea level. This is due to the high content of oligotrophes (3.94 mln. CFU/1g.a.d.s.), and pedotrophes (3.65 mln. CFU/1g.a.d.s.), including the species producing toxic exometabolites. In general, the virgin forest ecosystems are characterized by relatively low levels of phytotoxical activity of soil in comparison with the anthropogenic ecosystems.

Activity of soil microorganisms determines soil fertility, their environmental and phytosanitary status. In addition, soil microorganisms are indicators of contaminants in ecosystems, as reflected on the level of soil biological activity, including enzymatic activity and the intensity of emission of carbon dioxide from the soil surface. A high level of biological activity of the soil positively affects not only its structure, but also on the growth of plants [34]. The results of the biological activity of the soil by the intensity of emission carbon dioxide are presented on Fig. 3.

The high level of biological activity in the soil is characterized by virgin ecosystems. The intensity of emission of carbon ranged from 89-74 mg CO_2/kg.soil/day that indicates the favorable environmental conditions for the functioning of soil microorganisms. The biological activity of soil decreased with altitude increasing, due to the slowing of microbiological processes [35] and the reduction of the total number of soil microorganisms.

Microorganisms constitute nearly 1% of the soil mass and they have a major impact on soil properties and processes. Near 80% of the soil metabolism is due

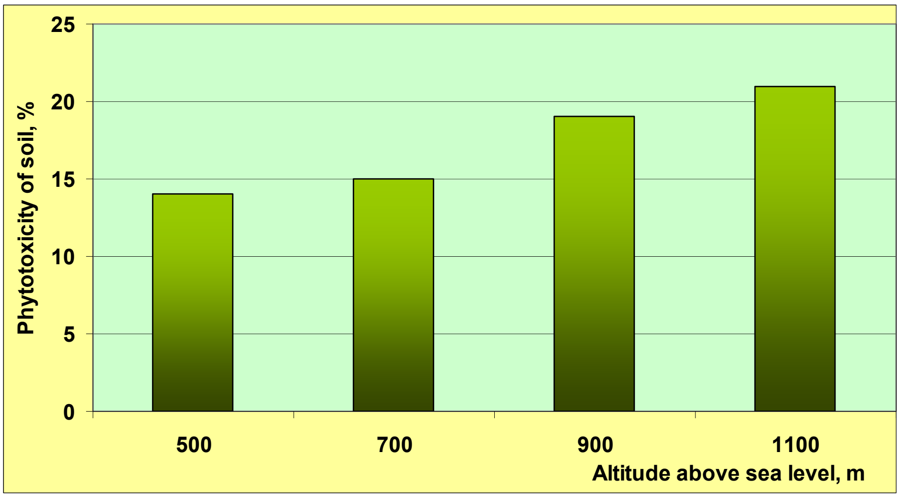

Fig. 2 Phytotoxical activity of soil in virgin beech forests of Shyrokoluzhansky massif of the Carpathian Biosphere Reserve.

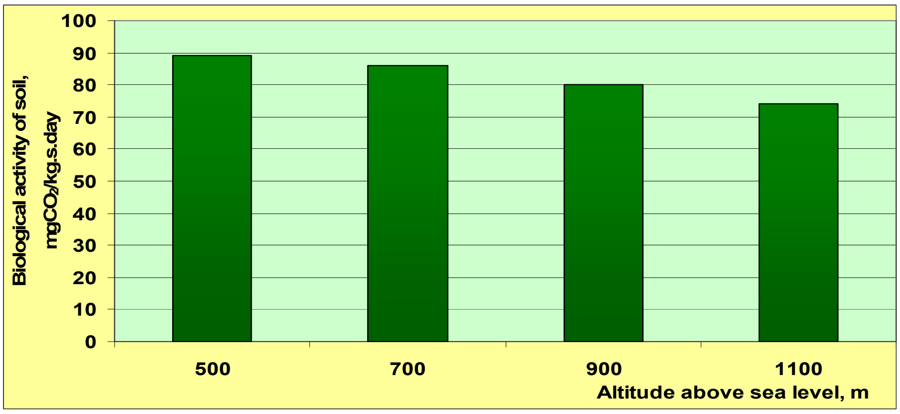

Fig. 3 Biological activity of soil in virgin beech forests of Shyrokoluzhansky massif of the Carpathian Biosphere Reserve.

Table 4 Stimulating properties of dominant bacteria isolated from soil of Shyrokoluzhansky massif of Carpathian Biosphere Reserve.

No.	Altitude above sea level, m	Amount of strains		Distribution of isolates by stimulating effect			
		Total number	Stimulators	Neutral	25%-50%	50%-75%	75%-100%
1	500	114	33	81	15	18	-
2	600	130	31	99	10	21	-
3	700	135	40	95	22	18	3
4	800	117	24	93	18	6	1
5	900	87	16	71	16	-	-
6	1,000	54	8	46	8	-	-
7	1,100	49	4	45	4	-	-

to the microbiota. The role of soil microorganisms in the biocoenosis relation to the plants can be both positive and negative. Some of soil bacteria are able to produce a variety of biotic substances with biocatalytic activity [36].

These bacteria activate biological processes in plants and, therefore, are called bacteria activators (stimulators). These bacteria increase germination, accelerate the growth of seedlings, roots, and sometimes even change the nature of the biochemical processes. Our task was to determine the stimulating properties of isolated dominating soil bacteria (Table 4).

During the study period were isolated 4 strains with high growth stimulating properties. These strains by morpho-cultural, physiological and biochemical properties belong to the species *Pseudomonas fluorescens, Pseudomonas putida.*

Various strains of *Pseudomonas* produced auxin-and gibberellin-like substances [37, 38].

The most active strains stimulated the growth of cotyledons (12%-90%), hypocotyl (2%-42%) and roots (12%-38%) Isolation the bacterial strains with growth-stimulating properties from the soil of primeval beech forests has a great practical importance, in the future they can be used to produce biopreparates for agricultural plants.

4. Conclusion

Consequently, the number of representatives of major ecological-trophic groups of the soil microorganisms varies depending on the altitude of forest's biotopes disposition above sea level.

The number of ammonificators and bacteria that use mineral nitrogen decreased with the altitude increasing, the number of oligotrophes and pedotrophes gradually was increasing. The level of the biological activity in the virgin forest's ecosystems was high. The intensity of emission of carbon ranged from 89-74 mg CO_2/kg.soil/day, it indicates about favorable environmental conditions for the soil microorganisms. Coefficients of oligotrophity and pedotrophity of the soil increased with the altitude and their maximum value were at the height of 1,100 meters respectively 1.29 and 3.00. Increasing of the pedotrophity indicates the intensity of decomposition of the soil organic matter, including humus substances.

Phytotoxity of the soil is informative parameter that should be used in the implementation of the soil monitoring research to evaluate the anthropogenic impacts on ecosystems. The phytotoxic activity of the soil was characterized by relatively low level in the primeval beech forests. The maximum level of phytotoxical activity (21%) was in the soil taken at the height of 1,100 meters above sea level. This is due to the high content of oligotrophes and pedotrophes, including the species producing toxic exometabolites.

Investigation of the biocoenotic activity of the native soil microorganisms is very important aspect. One hundred and fifty-six bacterial strains stimulators were isolated from the soil of the virgin forests of the Shyrokoluzhansky massif of the Carpathian Biosphere Reserve. The four of them have high growth stimulating properties.

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Use of Spatial Technologies to Study the Winds' Directions in Rub' Al-Khali Desert, Saudi Arabia

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Abstract: Studying environmental phenomenon in Rub' Al-Khali (Arabic name of "Empty Quarter"), as one of the largest deserts in the world, requires adopting some advanced spatial technologies in conjunction with the data recorded in the field in order to device better understanding. The paper utilizes the technologies of GIS (geographical information systems) and RS (remote sensing) in order to study large amount of weather data recorded in the field from different sources related to oil and gas industry in Rub' Al-Khali desert. The main objective is to identify the wind directions and its movement in Kidan areas and the areas south and east of Shaybah in Rub' Al-Khali desert. The study used different sources of data mainly recorded by the seismic campaigns' base camps and the drilling rig camps or the civil works camps. Wind Roses were created for all metrological weather stations in the study area. Also, the study tried to analyze the dune types using satellite imageries and identify the relation of its shapes to the wind direction. The final aim of the result of this study is to help in planning best locations to build facilities for new major oil and gas project.

Key words: Wind, oil, directions, roses, GIS.

1. Introduction

1.1 Sand Dunes and Winds' Regimes

Rub Al-Khali desert represents potential natural and large laboratory for studying dune fields and regional wind regimes. However, access to this desert is usually very difficult and requires large amount of logistical efforts and safety precautions. Moreover, some studies were even not able to access this desert due to political conflicts near to Yemen border [1]. Morphologies of the sand dunes in the deserts are significantly affected by the seasonal changes in winds directions. Consequently, formation of the dunes can be used as indication of winds regimes such as barchan dunes. However, it is very difficult to estimate winds in other types of the complex dunes such as star dunes that require at least tri-directional winds [2]. Understanding the winds regime in Rub al-Khali and knowing major wind directions in the study area is critical for any planned industrial development, especially for gas facilities as the gas leakage transfer easily with the winds direction. GIS-based literature plays an essential role in understanding potential wind energy in a map-based approach [3].

1.2 Background about the Study Area and Dunes' Types

The study area is located in the south eastern edge of Saudi Arabia, south of the UAE (United Arab Emirates) and west of the Sultanate of Oman border. It covers dunes in areas of Rub' Al-Khali desert such as Kidan, Shaybah, Zumal, Suhul and near Tumaysha. Topography of the Rub' Al-Khali desert south of the Arabian peninsula can be classified mainly into 13 to 15 different types which include: Barchanpoid ridges, Bedrock, Convergent dunes, Dome dunes, Draa or 'Uruq, Gravel plains, Hooked dunes, Megabarchans, Pyramidal dunes, Sand sheets, Seif dunes, Sigmoidal dunes and Small Linear dunes [4]. The study area (47,000 km^2) contains only 6 types of these dunes: Megabarchans (63%), Small Linear dunes (18%), Draa or 'Uruq (8%), Sigmoidal dunes (7%), Seif dunes (3%), Gravel plains (0.95%), and Hooked dunes (0.05%) (Fig. 1).

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1.3 Importance of the Wind Data for Oil & Gas Industry

Feasibility study of any giant oil and gas project needs to consider environmental aspects of the area of operations to support the critical decisions of the project. This would include for example the topographical information and weather data. GIS and RS technologies play major and efficient role in this aspect. Weather data are important for decisions related to dispersion models and plant/camps design. Having good understanding of winds' movements and energy will play major role in deciding best locations of huge investments such as CPF (central processing facilities) or remote stations. However, availability of the data in its own is not enough to support these decisions without implementing some processing and analysis to extract useful information. The real value of this analysis will be obtained when applying the spatial dimension to the study using GIS and RS.

1.4 Effect of the Wind Direction on the Shape of Dunes

The winds were very powerful during the colder intervals of Late Quaternary where storms during that period played major role in carrying huge amount of sand and accumulating it into the Rub' Al-Khali desert [4]. For example, the Megabarchans dunes which represent majority of the study area require continual wind supply from one direction to be formed. Similar case is with the "Small Linear Longitudinal dunes" where its long sand ridges are

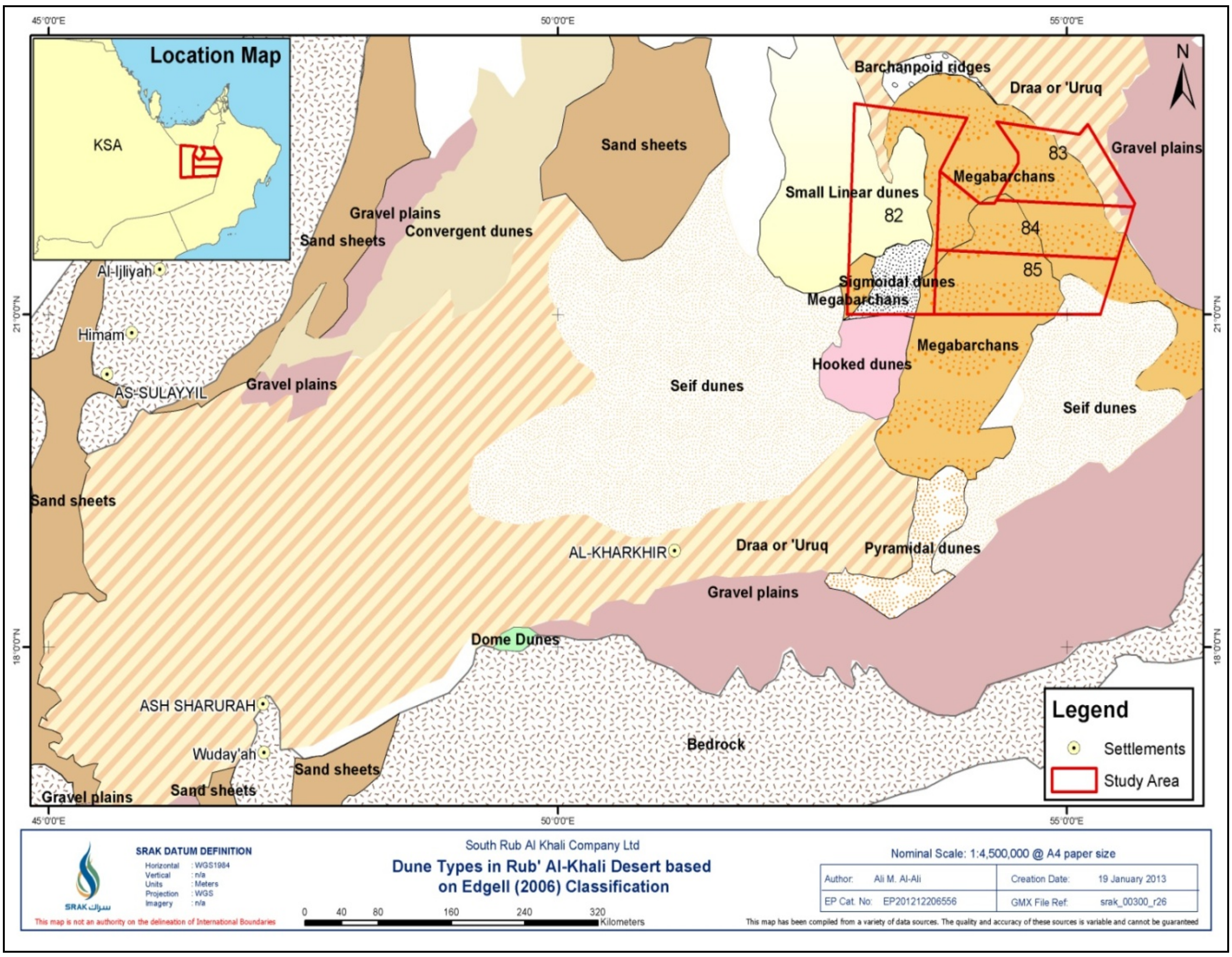

Fig. 1 Location map of the study area with regional dune types in Rub' Al-Khali desert digitized and reviewed by the author based on Edgell (2006) classification and using Landsat images as reference.

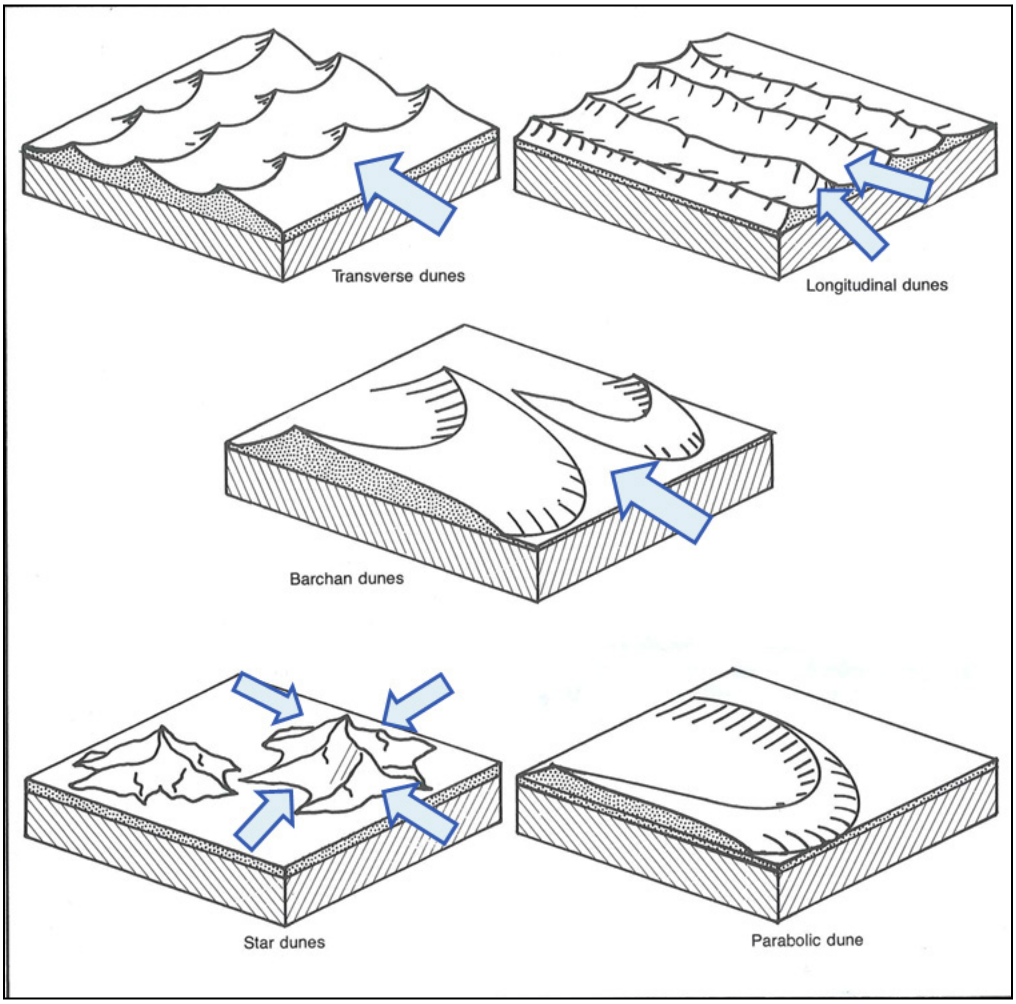

Fig. 2 Sand dune type, adopted from Link (2001)—Figure 206—Arrows added by author to the original figure to indicate possible wind directions.

parallel to the wind direction but angle of this wind is varying slightly and carrying limited sand supply within one particular direction [5]. On the other hand, for the Star dunes to be formed, it would require the winds blowing from different directions during seasons of the year [6]. Fig. 2 illustrates possible wind directions for some types of the dunes.

2. Methods, Materials and Results

The data used in the study were mainly either satellite data or field data. Both types of data were combined and overlaid in GIS environment for mapping and spatial analysis.

2.1 Satellite Data

It was important to acquire RS data for digitization, mapping and to recognize the different types of dunes. The study utilized two types of high-resolution commercial satellites imageries (Quick Birds and GeoEye-1) in some locations of the study area. However, it was not possible to buy the high-resolution imageries for other types of dunes. This was compensated by the acquisition of coarser satellite images from Landsat free mission. Fig. 3 clarifies the types and resolutions of satellite imageries acquired for each class of dunes in the study area.

2.2 Field Weather Data

The weather data were collected during the exploration operations of SRAK Company Limited (2005 to 2012). The metrological stations were

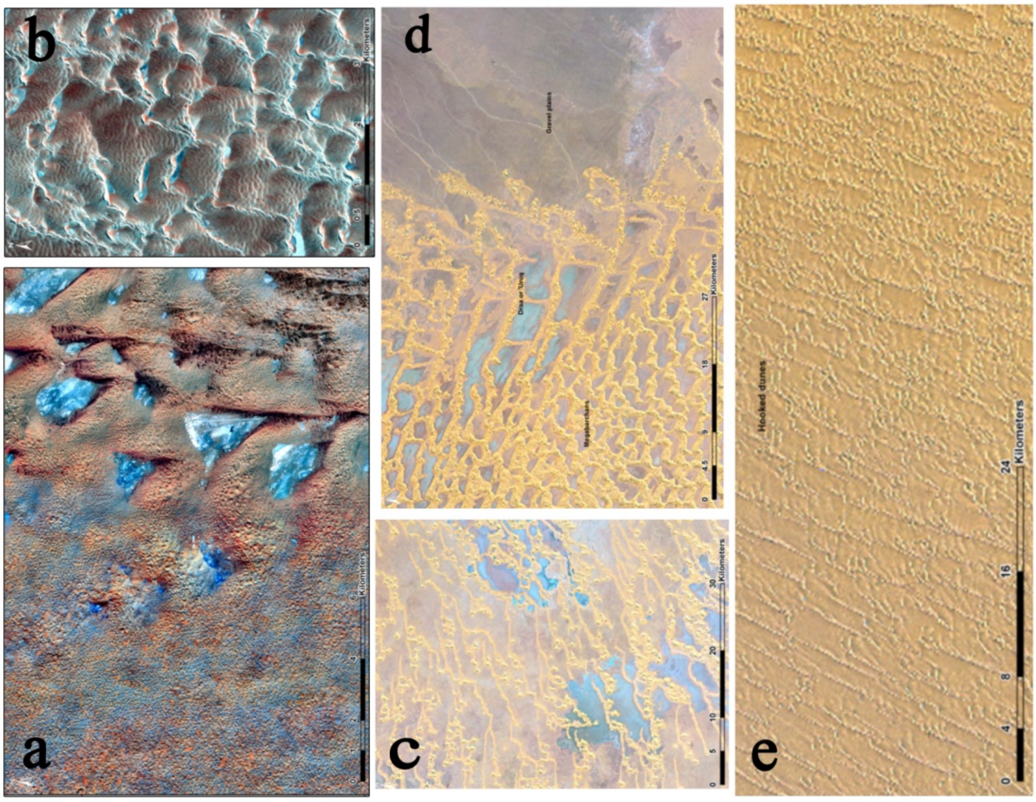

Fig. 3 (a) Quick Bird Satellite image (0.6 m) in Kidan North of Rub Al-Khali desert that shows two types of the sand dunes: Draa or Uruq dunes (lower side) and the Megabarachan dunes (upper side); (b) GeoEye-1 Satellite image (0.5 m) in Kidan South of Rub Al-Khali desert shows the Sigmoidal dunes; (c) Landsat Satellite image (143 m) in Southeastern of the study area showing the Seif dunes; (d) Landsat Satellite image (143 m) in eastern edge of the study area showing three types of dunes: Megabarchans (lower side), Draa or Uruq (middle side) and Gravel plains (upper side); (e) Landsat Satellite image (143 m) in southern of the study area (south of Kidan) showing the hooked dunes.

installed in the exploration well rig sites, seismic crew base camps, and civil works camps. The second source of weather data is Shaybah Airstrip (2006 to 2008). The third source is the NCDC (National Climatic Data Centre) during 1984 to 1986. This study is based on processing and analysis of data from 21 metrological stations using around 12,000 of the daily observations collected mainly in Kidan area during 2005 to 2012. The main data observed in each station include: wind direction, wind speed, and sometimes temperature, and humidity. Four zones were created to study the sub areas in more focused way as seen in Fig. 4.

Kidan north zone had the highest percentage (45%) of the daily wind observations with 5,667 records, while Shaybah South had the lowest portion (5%). The map in Fig. 4 shows the geographic distribution of metrological stations within each of the zones. Table 1 shows more details about these stations including M (main) and S (secondary) wind directions in each station.

3. Discussion

3.1 Processing & Analysis of the Wind Data

The processing focused on preparing the wind directional data and creating a wind rose chart for each metrological station. These charts indicated main wind directions' trend during a particular period of time. It also showed the average wind speed in each direction in addition to information about the geographic location and coordinates (see examples in Fig. 5). So, the next step was to study/analyze wind

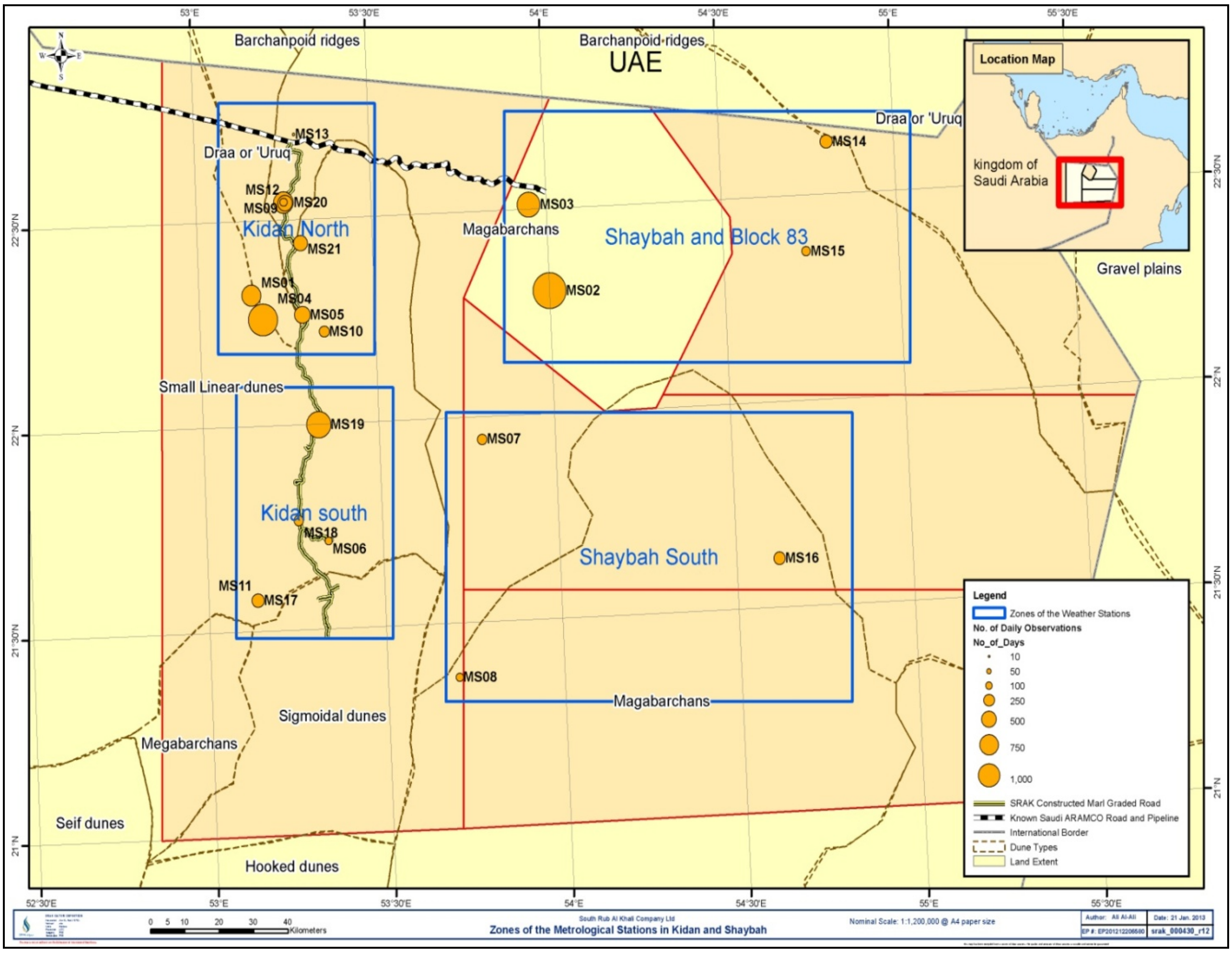

Fig. 4 Zones of the metrological stations in the study area (mainly Kidan and Shaybah areas).

Table 1 Details of the 21 meteorological stations used in the study.

Station ID	S_Name	Period	Daily Observations	M. Direction	S. Direction	Season	WGS84_Lat.	WGS84_Long.
MS01	Kidan	Oct. 2007 to Apr. 2011	792	NW	NE		N22 19 12.0	E53 09 00.0
MS02	Shawalah	Jan. 1984 to Oct. 1986 (NCDC)	2332	NW	NW		N22 18 00.0	E54 00 00.0
MS03	Shaybah Airfield	Jan. 2006 to Dec. 2008	1094	NE	NE		N22 30 43.9	E53 56 59.5
MS04	Worley Parsons	Jan. 2006 to Dec. 2010	1824	SE	NE		N22 15 36.0	E53 10 48.0
MS05	Kidan-7	Apr. 2008 to Sept. 2009	518	NE	N		N22 16 03.7	E53 17 33.5
MS06	Kidan-8	Nov. 2005 to Mar. 2006	120	NW	SW	Winter	N21 42 53.0	E53 20 41.1
MS07	SRAK 8 South of Shaybah	12-May-2011 to 11-Nov-2011	184	SE	NW	Summer & Autumn	N21 56 44.9	E53 47 28.0
MS08	SRAK-8 South East edge of B-82	12-Nov-2011 to 1-Mar-2012	111	NW	SW	Winter	N21 22 06.8	E53 42 04.2
MS09	Kidan North SRAK 1433	26-Jun-2005 to 26-Nov-2005	432	NE	SE	Summer & Autumn	N22 32 34.1	E53 15 17.0
MS10	Kidan North SRAK 1433	27-Nov-2005 to 4-Feb-2006	213	SW	NE	Winter	N22 13 31.0	E53 21 11.0
MS11	Suhul SRAK 1433	5-Feb-2006 to 18-May-2006	309	NW	SW	Spring	N21 34 35.0	E53 08 17.0
MS12	Kidan North SRAK 1433	19-May-2006 to 29-Jun-2006	126	SW	N	Summer	N22 32 39.0	E53 15 02.0
MS13	Shabita SRAK 1433	30-Jun-2006 to 5-Jul-2006	18	N	E	Summer	N22 42 32.0	E53 17 10.0
MS14	Zumal North of Block 83	1-Nov-2005 to 6-Mar-2006	336	SE	NW	Autums	N22 37 41.0	E54 48 24.4
MS15	Middle of Block 83	7-Mar-2006 to 4-May-2006	177	NW	NE	Spring	N22 21 48.0	E54 44 08.9
MS16	South of Block 84	5-May-2006 to 8-Aug-2006	288	NE	SE	Summer	N21 37 11.1	E54 37 14.9
MS17	Suhul SRAK 8615	9-Aug-2006 to 21-Nov-2006	318	N	NE	Autumn	N21 34 36.8	E53 08 16.1
MS18	North of Kidan South	Aug. to Nov. 2012	206	NW	NE	Autumn	N21 46 04.4	E53 15 43.8
MS19	Middle of Kidan	1-May-2010 to 31-Mar-2012	1224	NW	NE		N21 59 56.1	E53 19 39.2
MS20	North of KIDN-6	24-Oct-2007 to 30-Apr-2010	864	NE	NW		N22 32 37.9	E53 15 03.2
MS21	Kidan-6	29-Feb-2008 to 11-May-2009	440	NE	NW		N22 26 33.9	E53 17 40.8

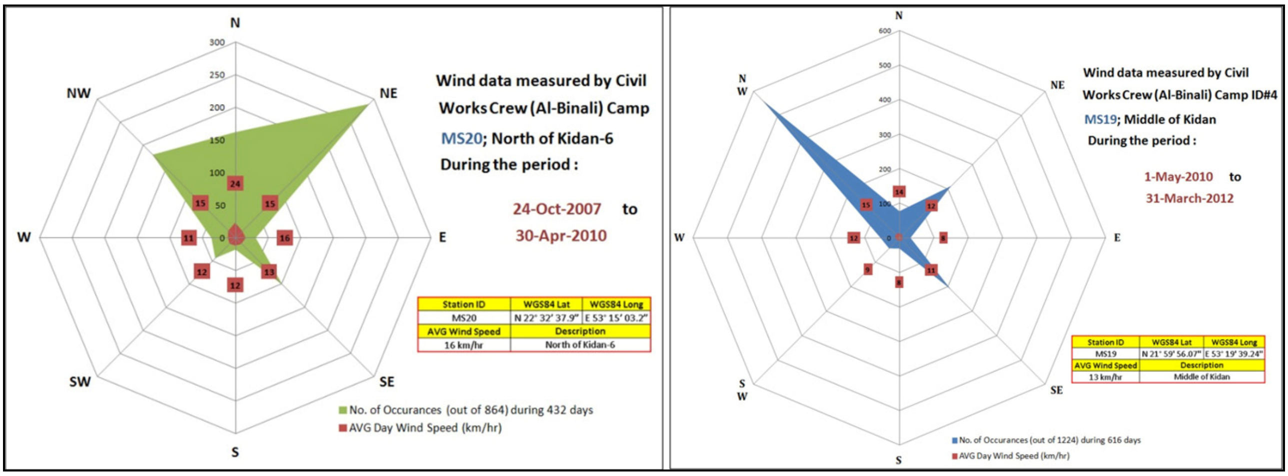

Fig. 5 Wind roses for the metrological stations: MS19 in Kidan South, and MS20 in Kidan North.

roses in each of the four metrological zones. Also, combining wind directions products with remote sensing products was very useful to get better understanding of the topography and its relation to the wind movements in any particular location.

Kidan North: the 9 metrological stations in this zone showed a visual trend of the winds that comes mainly from North and North East. This trend was based on 5,667 observations or 3,900 recording days during the period from June 2005 to April 2011. The map in Fig. 6 clarifies the main and secondary wind directions in each one of the 9 stations in Kidan North zone, where each arrow in the map represents one of the main directions in a particular station (with number of observation days annotated to the arrow). Fig. 6 also shows the wind rose compiled from the 9 stations for Kidan North zone. However, it is possible to go deeper and study data in any one of these meteorological stations. For example, the predominant wind direction in MS21 station was SE during March to May 2008. However, the predominant wind direction in this station was changed to NW during the three months (November 2008 to January 2009). But the highest wind direction frequency in this station is NE during the period February 2008 to May 2009.

Kidan South: the general trend in Kidan South is winds coming from North West apart from during the Autumn season where it is North winds. See wind rose of Kidan South in Fig. 7 to know more about other directions. This was based on 2,381 observations or 1,148 recording days from 5 different metrological stations in this zone.

Shaybah and Block 83: the main wind directions in Shaybah were North Eastern and North Western. Also, North Western trend can be seen in block 83 but based on limited amount of data, total of 171 recording days or 513 observations in two locations (MS14 and MS15).

Shaybah South: there was no real trend of the wind directions identified in this zone due to large area size and limited amount of data which was based on only 391 observations recording days. The three metrological stations in this zone were MS07, MS08 and MS16.

4. Conclusions

The final result after processing all available data in the study area showed that 59% of the wind in this area is coming from the Northern angle (NE, N, and NW), which were basically Shamal and Haboob winds. The Saus or Simoom winds, were secondly (26%), coming from East and South East directions. Figs. 8 and 9 clarify winds' names and their distribution/directions in the study area.

Shamal wind is a dry wind which carries large amount of dust and sand and occurs in both summer and winter but Shamal wind is more powerful during the daytime of the summer [4].

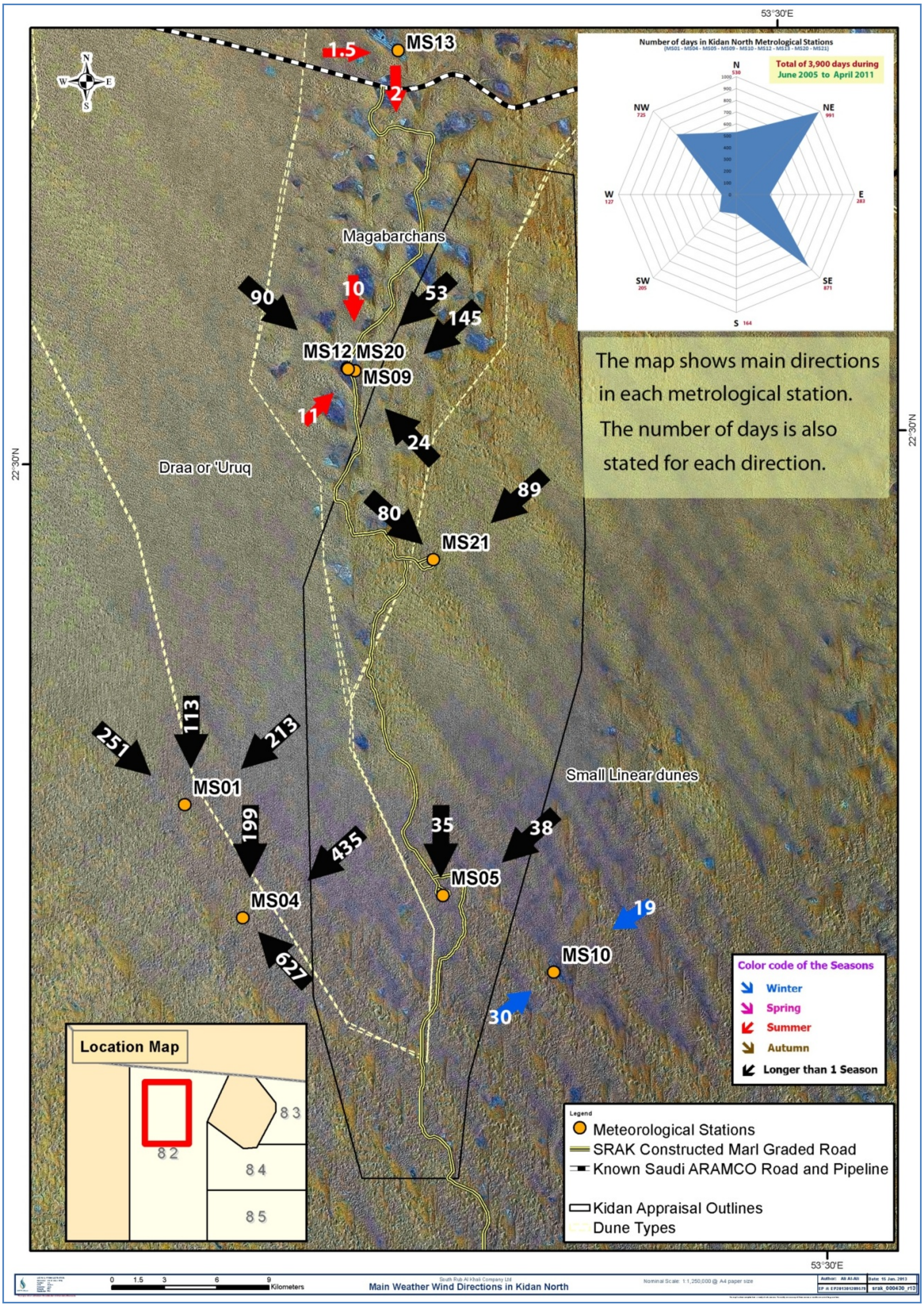

Fig. 6 Map of the main and secondary wind directions in Kidan North zone with wind rose.

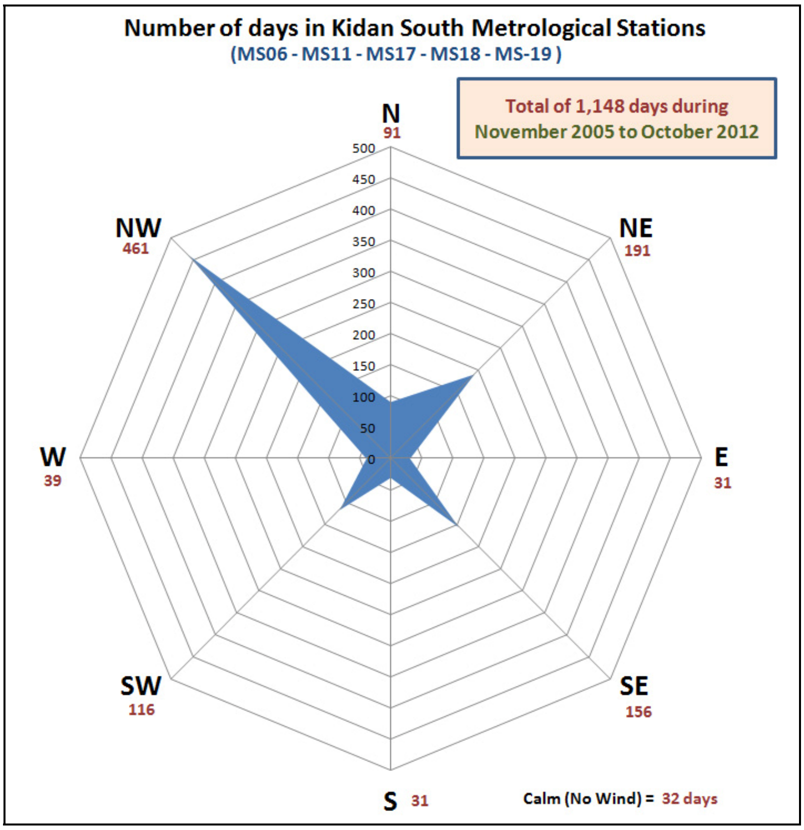

Fig. 7 Wind rose of Kidan South zone based on the number of observations (2,381) in 5 stations.

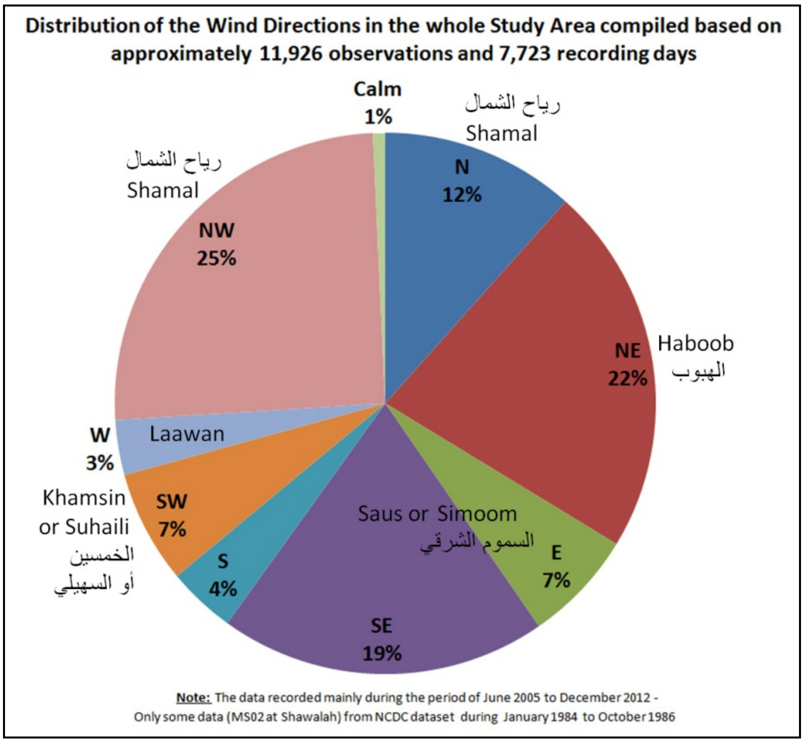

Fig. 8 Pie chart of the distribution of wind directions in the whole study area.

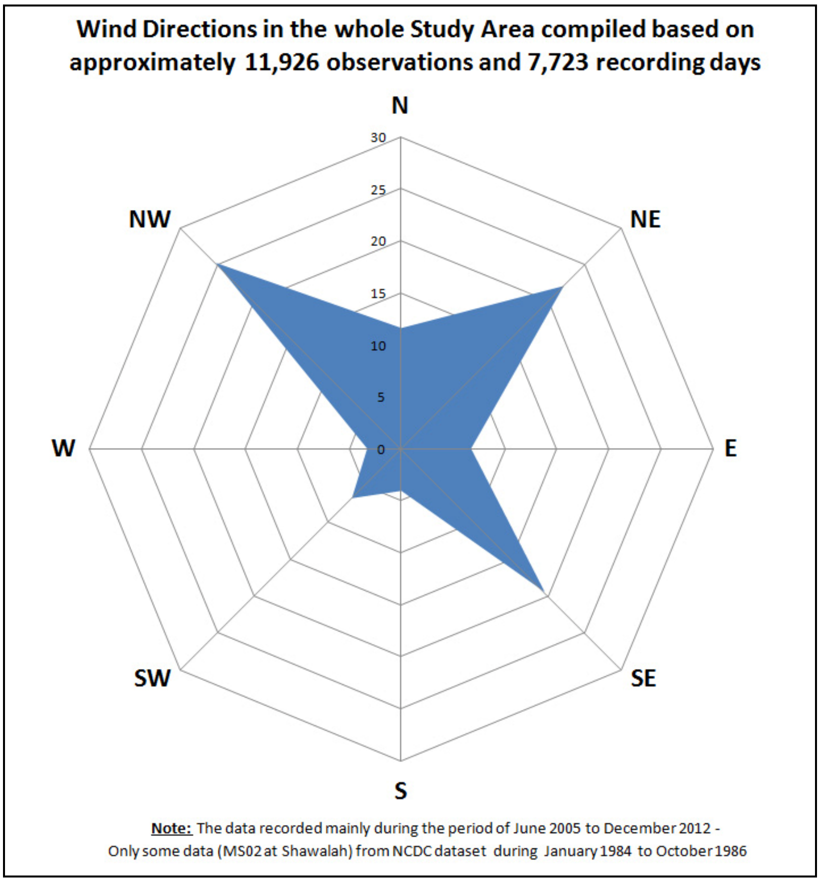

Fig. 9 Wind rose compiled from all data related to wind directions in the study area. Scale is percentage (%).

On the other hand, the Haboob is a storm that comes in a wall carrying dust and sand. Simoom is coming from North Africa as a violent hot dry and dusty wind while Saus wind blows as a low mild velocity wind.

Result of the study was plotted within the regional winds movement in order to get better understanding in larger scale on how these winds are moving? And from where they are coming? See Fig. 10 where study results are plotted in red color on top of the original maps from the Saudi Arabian Wind Energy Atlas (Al-Ansari et al., 1986, cited in Ref. [4]).

In conclusion, the study area has no main winds coming from the following directions: W, S, and E. The study also realized the importance of the winds coming from the northern angle (NW, N and NE). The season showed to have effect on the wind directions change. In Kidan North zone, the trend of the wind comes mainly from the northern angle and SE as Shamal, Haboob and sometimes Simoom winds. The general trend in Kidan South zone is Shamal wind (NW) apart from during autumn season where it is N. The remaining two zones (Shaybah and Block 83, and Shaybah South) were analyzed but no real wind trend can be guaranteed due to limited number of meteorological stations, large area size, and less amount of weather data. Finally, this study helped to understand the winds' movement/directions in Kidan which is critical to support future decisions related to dispersion models and when choosing locations of development wells and facilities especially considering the availability of dangerous gas such as H2S in the sub-surface. In other words, the study recommends that positioning of the main camps and facilities of the project to be in the N or NE of potential H2S sources. These positions will protect lives of the operators/workers of the project in case of gas leakage considering the main winds directions from northern angle and SE.

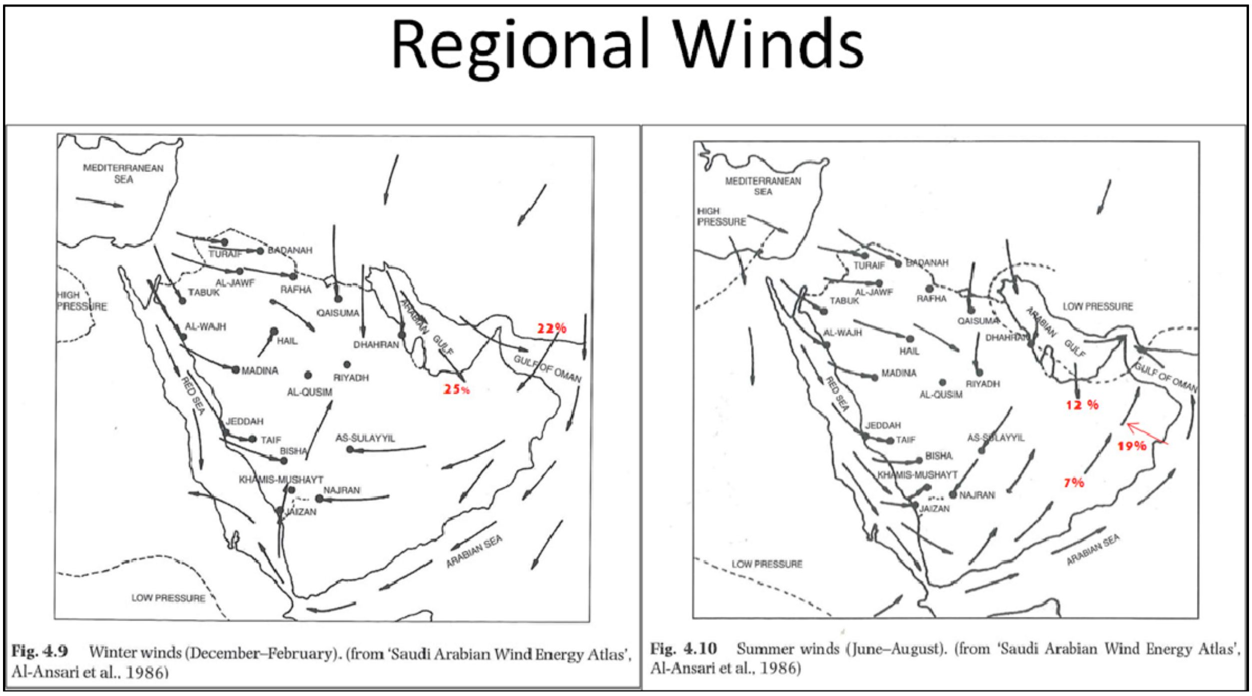

Fig. 10 Study result plotted in red color on top of the original maps from the Saudi Arabian Wind Energy Atlas (Al-Ansari et al., 1986 cited in Ref. [4]).

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Special thanks to the SRAK Company Limited, and the partners of this company (Saudi Aramco and Shell), who funded the whole data acquisition of the study. Thanks to the Ministry of Petroleum in Saudi Arabia, who approved the study initial release. Thanks to KACST (King Abdul Aziz City for Science and Technology) who provided some RS data. Finally, very special appreciation is given to all members of the field crews who collected this large amount of field data during many years of work, especially during 2005 to 2012.

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The Archaeologic Map and GIS in Ancient Topography Researches: The "Carta Archeologica d'Italia—Forma Italiae" Project

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Abstract: This paper presents the research method applied to the "Archaeological Map of Italy—Forma Italiae" project, comprising to date the *Ager Venusinus* project (completed) and the *Ager Lucerinus* project (ongoing). The idea of an Archaeological Map of Italy dates back to 1889 when by Royal degree the "Bureau for an Archeological Map of Italy" was created. Many decades later, with the advent of information technology and satellite observing systems (GPS) a "new era" of archaeological mapping began and the "*Forma Italiae*", thanks to these technological developments, began to develop the first Territorial Information System of archaeological matter in Italy. Between 1989 and 1992, studies and experiments were carried out on automatic systems for the acquisition, calculation and management of archaeological data relating to the Carta Archeologica d'Italia (Forma Italiae). Our project sought to put together many experiences, including some from the past, as part of a ministerial initiative resulting in the establishment of a committee; furthermore, it sought to extend the discussion that for many years concerned primarily academic institutions to the sectors dealing with protection and archeological prevention. Though it has been designed for prevention and protection, it simultaneously serves as the basic instrument for understanding and enhancement of the cultural resources of the territory. In discussions about preventive archaeology and about the so-called "archaeological risk", it is very useful to create a databank of the known archaeological heritage. For this purpose, a computerized system for data management was used, composed of a GIS platform associated with an alphanumeric archive and designed soon to become a web GIS.

Key words: Archeological map, GIS, GPS, survey.

1. Introduction

1.1 The Method of "Archaeological Map"

This paper presents the research method applied to the "Archaeological Map of Italy—Forma Italiae" project. This project is a joint effort of the University of Rome "La Sapienza", Cartographic Laboratory of Experimental Archaeology, Unione Accademica Nazionale, CNR and Archaeological Laboratory of Cartography at the University of Foggia[1] (Fig. 1).

Here presents two projects comprising to date the *Ager Venusinus* project (completed) and the *Ager Lucerinus* project (ongoing) (Fig. 2).

The idea of an Archaeological Map of Italy dates back to 1889 when by Royal degree the "Bureau for an Archeological Map of Italy" was created. Giuseppe Lugli's publication in 1926 of the first volume of *Forma Italiae* represented the continuation of the initial Royal project[2]. Many decades later, with the advent of information technology and satellite observing systems (GPS) a "new era" of archaeological mapping began and the "*Forma Italiae*", thanks to these technological developments, began to develop the first Territorial Information System of archaeological matter in Italy.

This method was also used in the Project

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[1] Project leader: P. Sommella with me. For CNR: M. Mazzei.
[2] Castagnoli 1979; Sommella 2009, 47-59; Marchi et al. 2015.

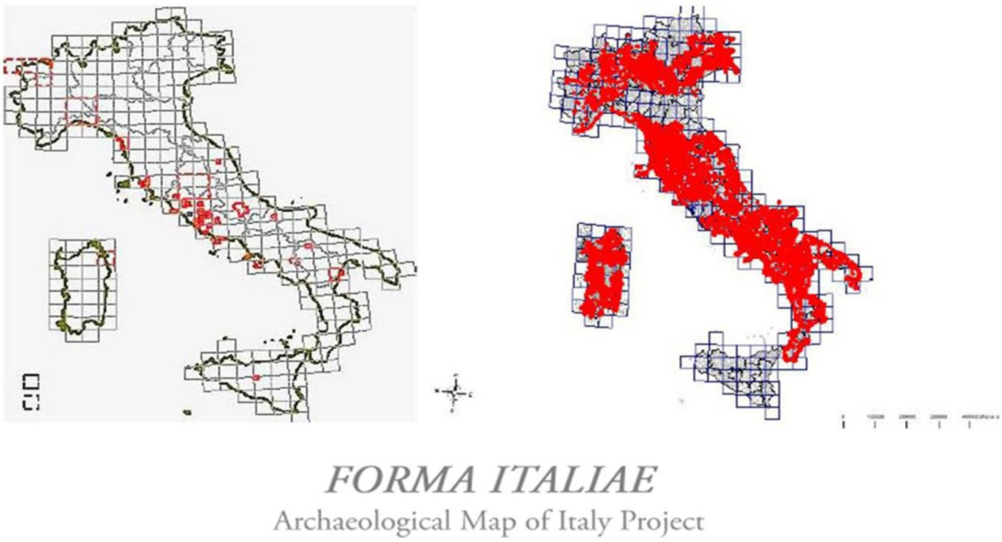

Fig. 1 Forma Italiae project (GIS).

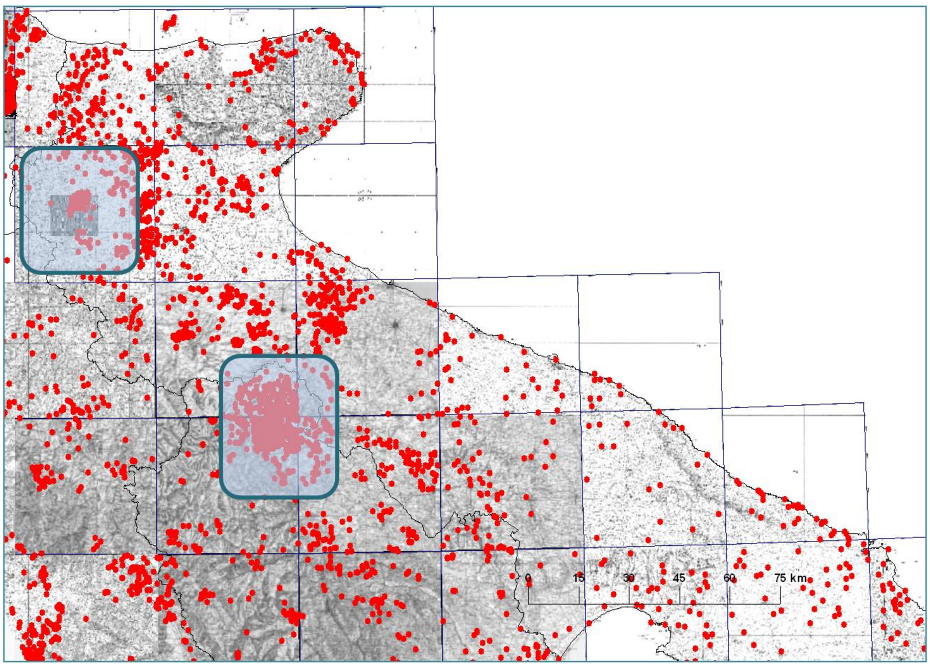

Fig. 2 Ager Venusinus and Ager Lucerinus project.

"*Repertorio bibliografico per la Carta Archeologica della Provincia di Roma*"[3] and also in the "*Project Census for an Archeological Map of Italy*"[4].

The "Project Census for an Archeological Map of Italy", was carried out over several years (2002-2008) to create a new scientific and technical tool based on the work done previously in relation to the "Archeological Map" of Italy.

The importance of an archeological heritage database is reinforced by the discussion on preventive archeology, and more in general on "archeological risk", a topic currently considered of great relevance.

The "Project Census for an Archeological Map of Italy", started in 2002 on input from the "The Ministry

3 Amendolea 2003; Marchi 2005.
4 Marchi 2012.

of Cultural Heritage and Activities", in collaboration with Sapienza University of Rome, with the participation of the University of Foggia, and was carried out in several operative phases.

The project allowed for the realization of a large integrated system, for protecting the heritage and preventing damage to it. The project further, provided an essential instrument for better knowledge and greater valorization of the cultural heritage on Italian territory (Fig. 3).

The program provided a "Register", based on the cataloguing and georeferencing of bibliographic and archive material. The census involved all of Italy, with the exception of some autonomous regions with special status and Emilia Romagna, that had its own informative system for many years. The work progressed in phases, starting with the central-southern regions and finishing with the northern regions.

The project also involved an updating for the regions subjected to census in the early phase (Basilicata and Campania) and in general a continuous updating.

The census of the archeological elements is based on published material for which a topographic localization on a map is possible. To insure the reliability all data, will be verified on site, the archeological elements were selected based on two levels of trustworthiness: georeferencing and general localization.

The project led to the census of almost 30,000 archaeological sites, chronologically ordered from Prehistory to the High Middle Ages.

The "Archaeological Map" helped us reconstruct the historical archeology of the ancient landscape from Prehistory to the High Middle Ages and promote the protection and cultural appreciation of the territory.

2. Materials

2.1 The GIS for "Forma Italiae" Project

While not being a determining factor, the great experience of research in the Venusinus gained in twenty-year periods especially since information technology began to be integrated in most territorial documentation has facilitated everything explained above. So experimenting with the "automatic" passage of information from direct reading of the land to the operational project but without specialist interpretation was begun in topographical research as well as in the selective reading of both urban and territorial themes[5] .

This was one of the first archeological projects in Italy to use GIS, experimenting with database input and with GIS applications. Our project, which included the creation of a dedicated GIS (Carta Archeologica d'Italia: Archeological Map of Italy—*Forma Italiae*)[6] (Fig. 4). It is important to keep in mind that having the entire project with all its analytical data in the GIS makes cartographic references and indications of scale superfluous. All archeological elements, both monumental and structural as well as scatter of material on the surface are georeferenced, their shapes and sizes perfectly represented.

Another distinguishing characteristic is that subjects can be selected from chronological phases inside geographical boundaries (regions, provinces, communes[7], or individual locations), or by type of archaeological find (villas, necropolises, built-up areas etc.) from both the graphic (visualisation on the map) and alphanumeric points of view.

Archaeological points have been catalogued by issuing data in site reports/bibliography and site/recognition reports appropriately processed using a process based on lengthy experimentation with computerised cartographical methods and devices based on many years of data processing experience. The contents are adjusted to the stability parameters of

[5] Sommella 2009; Azzena 2009.
[6] Marchi, Mazzei 2012; Marchi et al. 2015.
[7] Commune (Municipality)—the smallest administrative division in France and Italy governed by a mayor assisted by a municipal/local council.

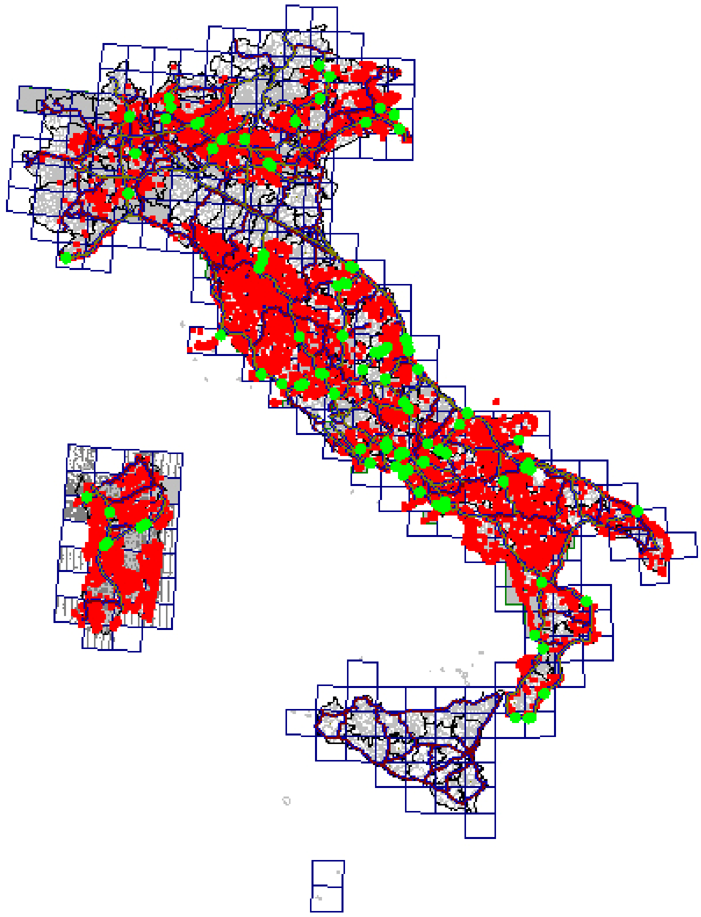

Fig. 3 The "Project Census for an Archeological Map of Italy".

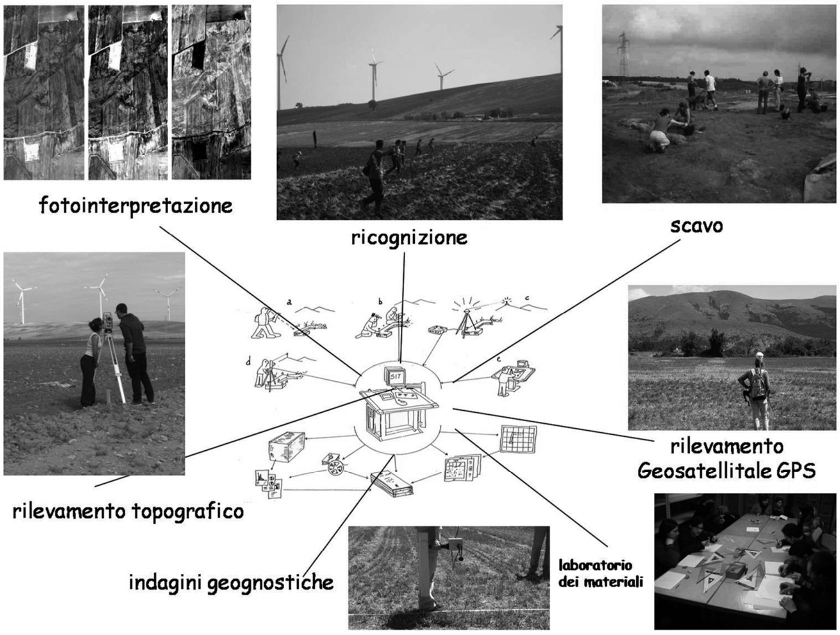

Fig. 4 The structure of GIS "Forma Italiae".

the MiBAC[8] Joint Committee[9] and compatible with the ICCD[10] cataloguing standards above all with regard to the identification parameters. All of the items on the report are found in dictionaries contained in the drop-down menu, and these are also processed on the basis of the ICCD directive and the lengthy experience acquired from modelling experiments[11] (Fig. 5).

One of the most important factors is the input of archaeological constraints as preferences[12].

The large volume of data collected (over 3,000 reports) between the end of the 1980s and the year 2000 has facilitated the refining of methods and techniques in a continuously evolving system, and data processing has been connected with experimentation on report/graphic apparatuses for both the finds and the sites where the finds were made.

Our project was also one of the first to work with GPS (global position system)[13]. Between 1989 and 1992, studies and experiments were carried out on automatic systems for the acquisition, calculation and management of archaeological data relating to the *Forma Italiae* (Fig. 6).

The digital information collected makes analysis of the distribution of archaeological finds as a function of the chronological phases possible as well as the study of the dynamics of settlement of the historic landscapes and provides indicators able to reveal hidden or unexpected characteristics found when complex territorial systems such as historic ones are analysed.

The system facilitates in-depth investigation of the distribution maps of various settlements and their relationships with other sites as well as the exploitation of the spatial analysis techniques together with other information sources so that extremely useful critical items can be caught in the territorial planning phase. This GIS project has proved useful in both scientific activity and the census needs of organisations that value and protect cultural heritage.

Moreover, it must be emphasised that the GIS presented is the result of a very lengthy process of experimentation. The examples only represent some of the potential that the system offers for researchers. All of this is only the starting point and not the purpose of the research and the aim is the historical reconstruction of the territory and its landscape.

The Ager Lucerinus Project is interesting from this point of view as it concerns a territory whose ancient landscape was varied and articulated, and the archaeological map produced is a valid instrument in protecting an area continuously threatened by the diffusion of aeolian deposits. In fact, the GIS data processed by the Archaeological Cartographic Laboratory in accordance with the Superintendency for Archaeological Heritage in Puglia was used as a support for the *Piano Paesaggistico Territoriale della Regione Puglia* (PPTR)[14] (Fig. 7).

The great many applications of information systems in the archaeological-topographical sector are above all a result of them being an instrument that solves a wide range of problems with management and data analysis methods. What characterises an archaeological GIS is not so much its content, that is, the data that is manages, but its ability to interpret the data. Dedicated GIS has been made for many years that can be defined as an archaeological attempt to understand the meaning of the objects from which the data come, so an additional phase compared to what is used to recover the data using conventional GIS is necessary: a phase of interpretation. Another difference

[8] MiBACT (*Ministero dei Beni e delle Attività Culturali e del Turismo*)—Ministry of Cultural Heritage and Tourism.
[9] Carandini, 2008.
[10] ICCD—(*Istituto Centrale per il Catalogo e la Documentazione*)—The Central Institute for Cataloguing and Documentation within the Italian Ministry of Heritage and Culture (MIBAC), defines procedures, standards and tools for the Cataloguing and Documentation of national archaeological, architectural, art history and ethno-anthropological heritage in agreement with the region.
[11] Azzena, Tascio 1996.
[12] Marchi, Mazzei 2012.
[13] Azzena 1992, 747-66.
[14] Puglia Regional Territorial Landscape Plan.

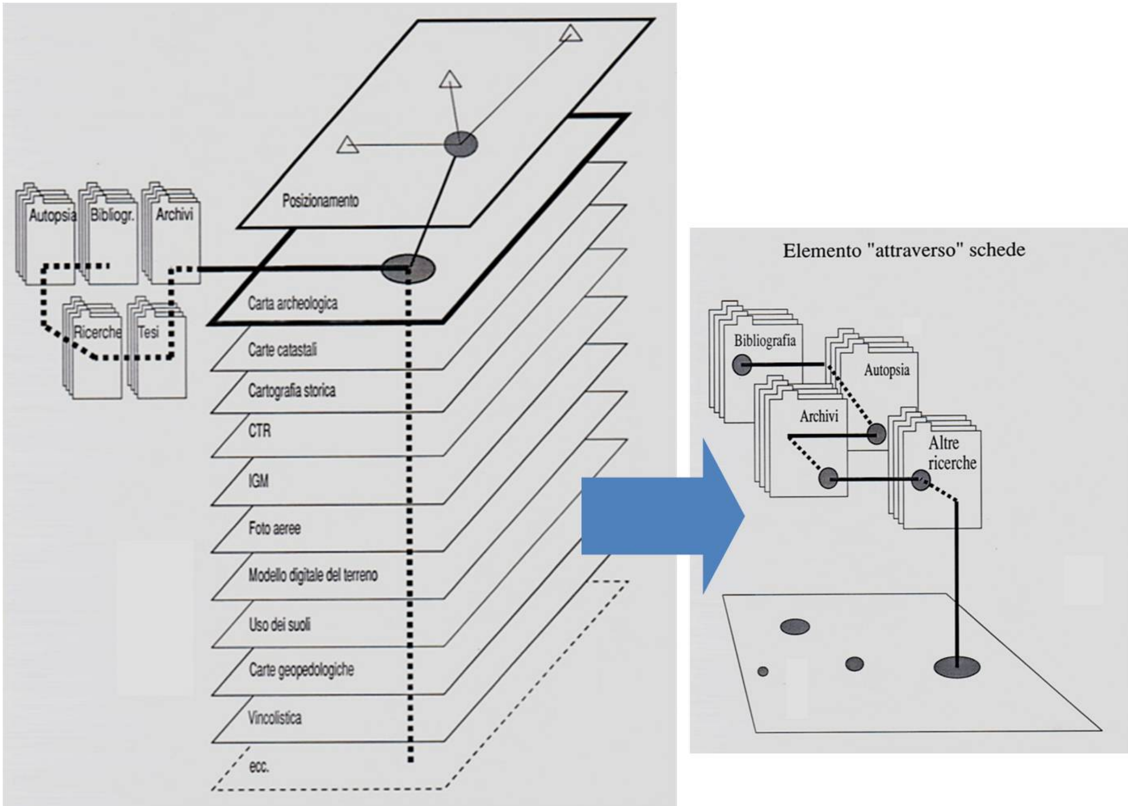

Fig. 5 The structure of GIS (from Azzena, Tascio 1996).

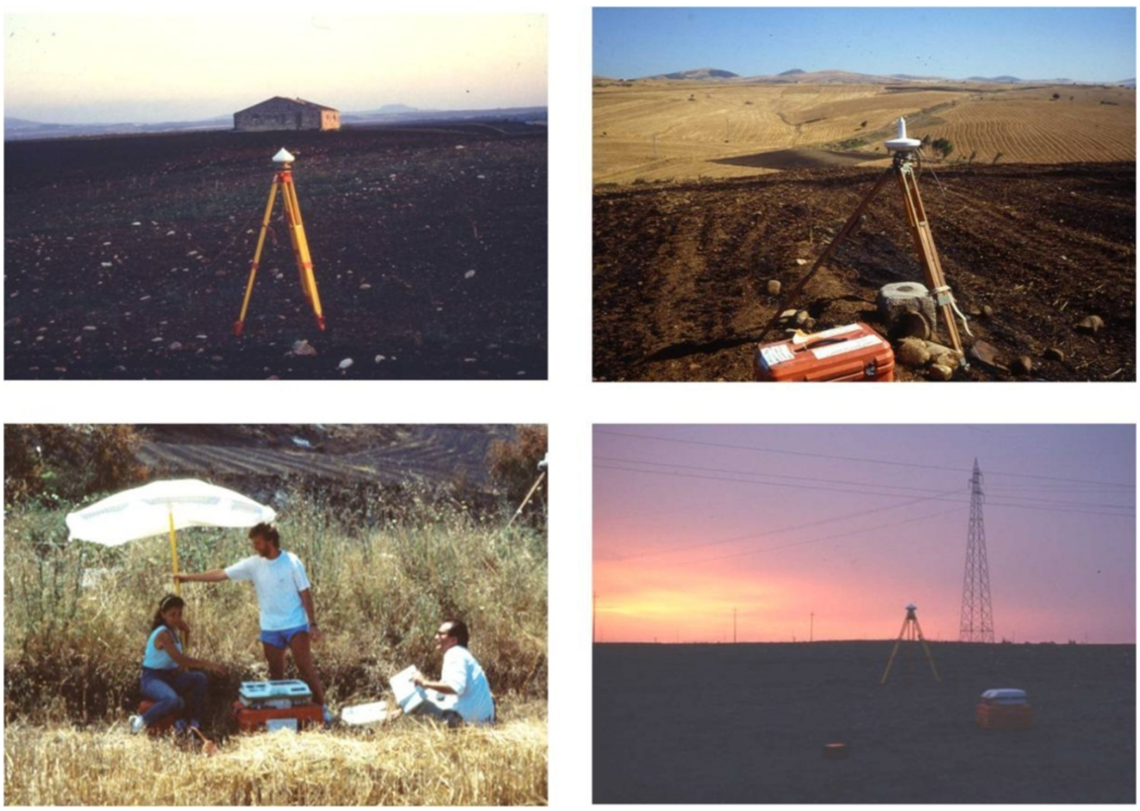

Fig. 6 GPS in archaeological field survey: 1988-1989.

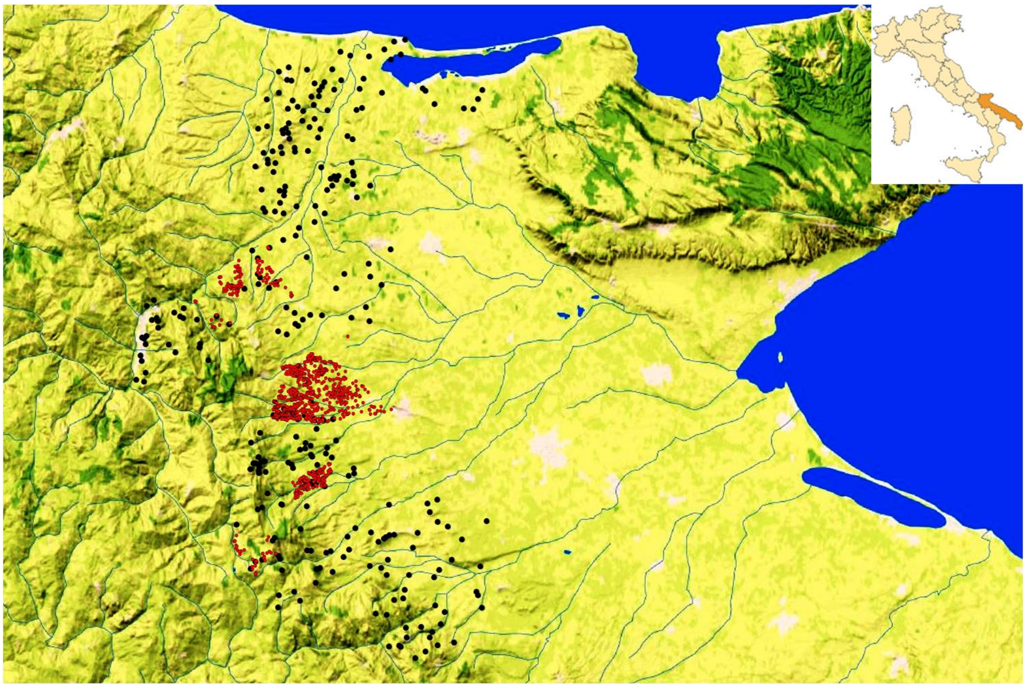

Fig. 7 The Ager Lucerinus project: DTM (Cartography Laboratory of Foggia).

compared to most conventional GIS is the use of three-dimensionality in developing models of the territory. In fact, it is clear that when an attempt is made to understand the behaviour of ancient man, one of the most important variables is the landscape with which he interacted and people still interact. Therefore, modelling the space as realistically as possible is a fundamental prerequisite in checking, using algorithms that were not developed for archaeology but when combined together appropriately, assuming that the deductions about the archaeological remains made are reliable to some degree. Therefore, the GIS used in the study presented in this paper is also often based on three-dimensional models.

Several characteristics and peculiarities of the construction and implementation of the GIS for the Archaeological Map of Italy—Forma Italiae are now examined.

In the initial phase, we used a multiple source data retrieval approach (bibliographic, archival, epigraphic, archaeological, etc.), recording much of the information reducing it to generic symbols, distinguishing only location type (precise or generic), but the scarcity of material gathered in the early stage of the project made clear the need for a more detailed survey of the territory itself.

Orthophoto supported by the regional GIS (*Carta Tecnica Regionale*[15]) (Fig. 8) is the cartographical base reference (just as for the National Geoportal, in this case reference has been made to the free services available on the web site http://www.sit.puglia.it), while the cadastral map has always been considered as it is indispensable to the taking of protective measures although little used in the operational phase because it lacks altimetric references and is often absolutely anacronistic. As previously confirmed, the 1:25,000 scale IGM[16] map is an unsurpassable base reference for the global picture and is more useful in several situations as historic cartography than direct reference on the terrain.

Aerial photographs were fundamental in identifying archaeological evidence such as crop marks in the

[15] The general GIS of the region is the Regional Technical Map (*Carta Tecnica Regionale-CTR*) at the scale of 1:10,000. The source of the data is aerial photos or in some cases satellite images (layer "Use of the soil"). The mathematical elaboration of these produces the detail of these maps in urban blocks.

[16] IGM (*Istituto Geografico Militare*)—the Italian military geographical institute.

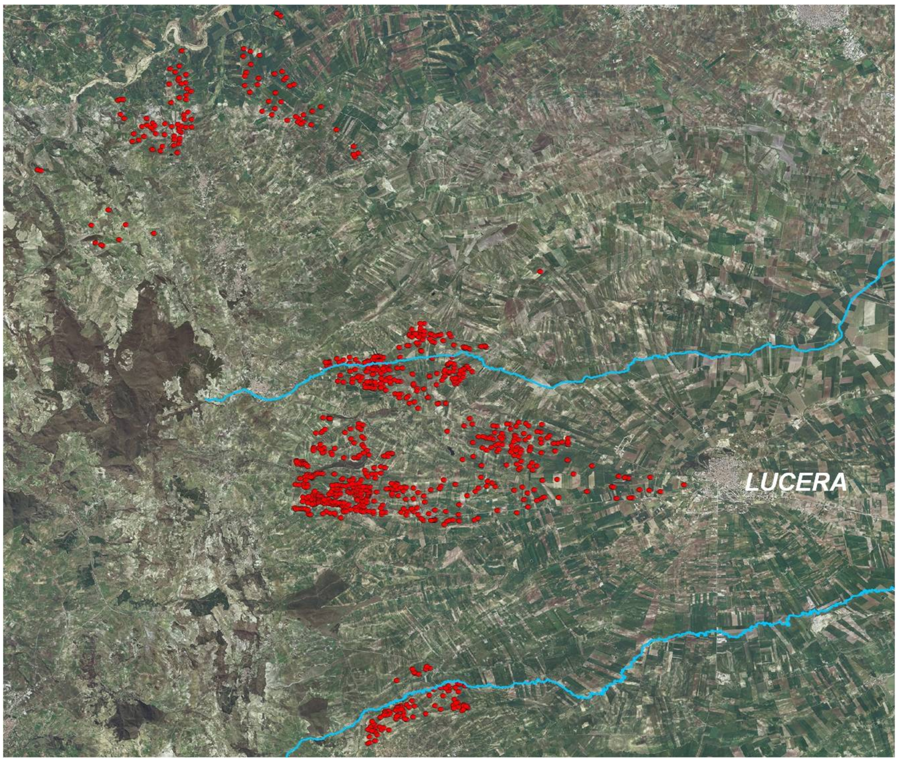

Fig. 8 The Ager Lucerinus project: Orthophoto.

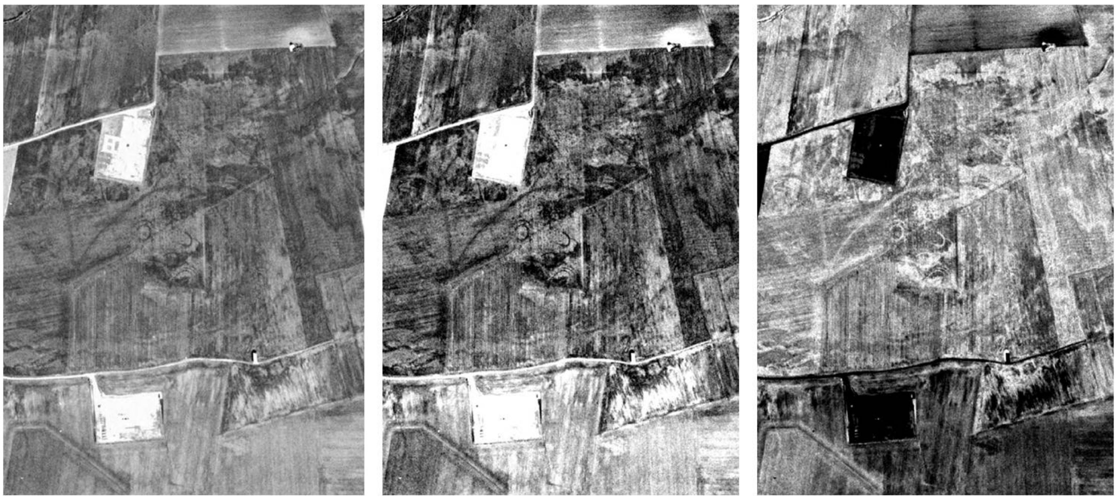

Fig. 9 The Ager Lucerinus project: Aerial photographs.

territory. The material from the RAF photographic coverage for the area (1943-47) and from IGM were unquestionably useful (Fig. 9).

The aerial coverage currently available (1954; 1988-89; 1994; 1998; 2000; 2004; 2007; 2010) was compared in order to check how legible the traces are through time. It should be noted that some of the above-mentioned series of aerial photographs, available for reading and analysis using the GIS, are directly usable on line through the OGC (Open Geospatial Consortium), previously known as the Open GIS Consortium, an international not-for-profit organisation based on voluntary agreement which defines technical specifications for geospatial and location based services. In particular, the method used to implement the Ager Lucerinus project not only made use of aerial photographs but also WMS, WFS, and WCS services present on the National Geoportal (www.pcn.minambiente.it). Using a procedure in the project GIS software (that is, proprietary: ESRI ArcGis, Geomedia, and *free*: QG is) through which the information layer can be coupled and projected *on fly* (only with an Internet connection) inside the project presented in this paper as a very normal information layer. In addition to clear financial and time savings, this procedure obtains updated georeferenced data with very high quality standards.

Geomagnetic or electromagnetic prospecting is also carried out in some cases in order to introduce further information on submerged presences, often contributing precious items in the reconstruction of building plans.

The reading and where possible the georeferentiation of the historic cartography are absolutely necessary for the recovery and analysis of items in the landscape above all in the historic reconstruction of infastructures such as the road network or geomorphological evolution and changes in the landscape. Therefore, a series of historic maps was also regenerated, georeferenced, and lastly analysed in the project presented in this paper including precious historic and documental historic maps such as the Rizzi Zannoni, the "Locations" of the "Foggia sheep Customs House", and all of the IGM cartography productions. In addition to the recognition investigations, topographical sampling is always carried out so that finds identified using GPS georeferentiation are correctly positioned (Fig. 10).

The large number of documents represented by the areas of mobile material fragments means the reliability of the data is very closely connected to how visible the terrain is which in turn depends on the type of cultivation and the degree to which the land has been worked. So when choosing the moments of maximum legibility, the maps of the visibility/legibility and use/condition of the soil need to be processed so that how reliable the data gathered is can be defined and a solid base for reading the archaeological presence/absence can be composed, consequently creating the assumptions on which an interpretation and a qualitative standard can be based[17].

The attention given to the DTM (Digital Elevation Model) processing obtained by interpolating the contour lines has facilitated hypothetical three-dimensional reconstruction of the ancient landscape and so its "virtualisation". It also makes it easier to perceive and identify systematic forms of anthropic settlement and to formulate further research hypotheses about the presence of human life and buildings in a determined altimetric position or its slope and exposure in relation to the surrounding environment.

In particular, time has been dedicated to creating a Geodatabase in the ArcMap environment. The geodatabases not only support featureclass, rasters, and attributes, they also allow advanced GIS data behaviour and integrity rules to be implemented using types of data such as the topologies, networks, raster catalogues, terrain, specific rules for cadastral data (cadastral fabric), relationships, subtypes, and domains. The geodatabase unites "geo" (spatial data) with "database" (data repository) to create a central repository to manage and memorise the spatial data. This makes it possible to save the GIS data on a central server in order to facilitate easier management and rapid access. The construction of Geodatabase allows a very detailed implementation of the data input and so the equally detailed running of queries in the GIS constructed in this way. In other words, the more complex, the more detailed, and the more organised the attributes of any type implemented in the geodatabase are, the much more detailed, accurate, and exhaustive will the answers produced by the software be, making it possible to create the assumptions for as objective and immediate an interpretation as possible.

[17] Marchi 2010.

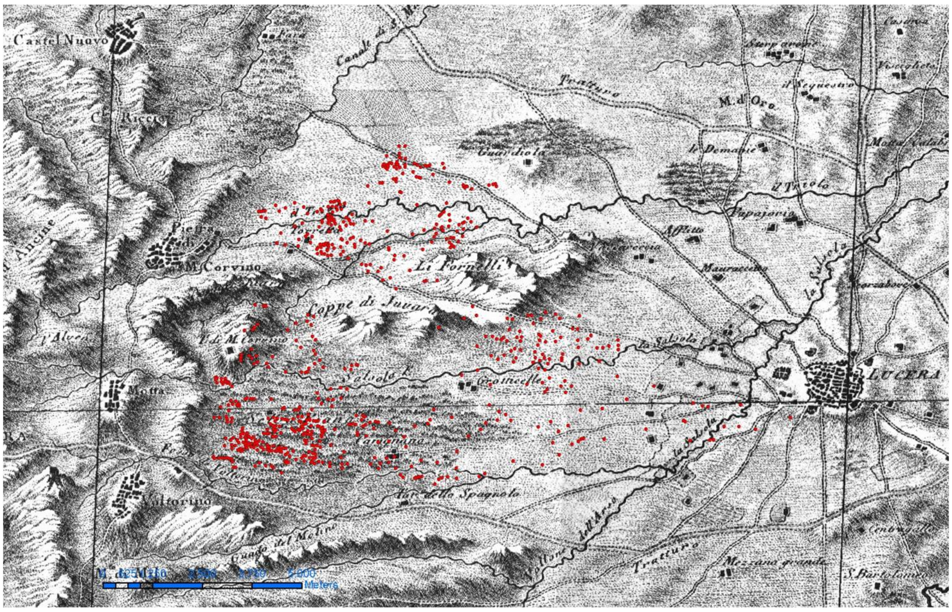

Fig. 10 Temathic map: historical maps.

For this purpose a computerized system for data management was used composed of a GIS platform, associated to an alphanumeric archive and designed to soon become a web GIS.

2.2 The Survey Methods

The archeological survey covered all the phases of territorial occupation, according to the criteria of systematic methodology. This type of survey is considered more useful than one restricted to a particular chronological period.

Our research was carried out according to the scheme established for the *Forma Italiae* using the IGM (Istituto Geografico Militare—the national mapping agency for Italy) 1:25,000 maps in the field we used the Regional Technical Map (Carta Tecnica Regionale, CTR) available in a scale of 1:10,000 or 1:5,000.

For some towns, but not all, digital aero photogrammetric maps are available. In many cases, it was possible to integrate orthophotos. In all cases, we used cadastral maps, which are fundamental for determining areas that should be protected, even though they contain no altimetric information and are sometimes outdated, for which reasons they are not easy to use in the field.

The mass of data gathered (more than 3,000 items for the Ager Venusinus project and 1,200 points for the Ager Lucerinus project) allowed us to refine techniques and methods for constructing a database. We experimented with many formats for entering data regarding both sites and materials.

The main objective determining our methodologies was that of gathering extensive, intensive and systematic data, completely covering the chosen territory (Fig. 11). The debate regarding topographic research methodologies was quite intense, the controversy pitting them against sampling survey methods. Our research results clearly demonstrated the validity of our methodology, which allowed us to obtain 90% more information regarding the starting point, in the areas where we gathered data, we were able to identify the existence of a much older settlement than what the published data indicated, with a ratio of 1 to 50 concerning published and unpublished data[18].

In the initial phase, we used a multiple source data retrieval approach (bibliographic, archival, epigraphic,

[18] Azzena, Tascio 1990, 207-22; Marchi, Sabbatini 1996; Tartara 1999; Quilici, Quilici Gigli 2001; Quilici, Quilici Gigli 2003, 28-31; Marchi 2005, 80-81.

Fig. 11 The survey.

archaeological, etc.), recording much of the information reducing it to generic symbols, distinguishing only location type (precise or generic), but the scarcity of material gathered in the early stage of the project made clear the need for a more detailed survey of the territory itself.

Following the "Forma Italiae project" methodology, based on an extensive and systematic survey of the whole selected district, the countryside systematically scanning the countryside on foot (the team consisting of 3-5 researchers), and returning to some areas in different seasons, though, when the ground was in different states of cultivation, in different weather and visibility conditions and at different times of the day.

Most sites were indicated by dense scatter of material on the surface. In these cases our date collection efforts per force had to take into account when the terrain had maximum visibility which depended on the type and stage of cultivation. This approach allowed us to create a map of visibility of the territory.

Since cereals predominate in the farming of the fields in the territory we were researching, the ideal period for our investigation was from the end of the summer through the autumn when the fields had been harvested, thus offering the greatest visibility. Where grapes and olives are farmed, as where the fields are not farmed, the best periods are winter and spring. We classified the areas where we found scatter according to size and density of scatter.

It is important to note that when indicating the size of an area, we considered only the zone with the greatest concentration of material, where excavation was most likely to reveal structures.

We have had to consider theoretical and methodological implications of the classification of archaeological in regional survey archaeology, and the potential of classifications for making intra- and interregional comparisons and interpretations. The definition of a site is difficult, not in the least since everyone believes they know what it means, yet many definitions exist[19].

[19] S. Plog, F. Plog, W. Wait, for instance, define "sites" as discrete and potentially interpretable loci of cultural materials. For the geographer W. Wag staff, a site is "fundamentally a

We were able to define the types of settlements for sites of the Roman period (rural structures, farms, *villae*, *vici*) by combining the following types of data: size of the area, characteristics of the scatter, that is, whether construction materials (bricks and tiles, building stone, clay, etc.) or decorative elements (floors, plaster). In general, in the case of small areas, less than 100 sqm, but often also of larger ones, from 100 to 200 sqm, containing very poor building materials suggesting the presence of walls made from perishable materials, we opted to use the term "rural structure", by which we mean, using the terminology of ancient Roman sources[20], casae or tuguria[21] or villulae[22]. We used the term "farm" only for large areas where we found documentation of specific agricultural activities. We identified as "villas" areas larger than 1,000 sqm presenting multiple structures, each with a different function (residential, productive, storage), and scatter of high quality materials (marble, mosaics, etc.).

Further on our terminology, we analyzed the concepts of "topographic unit"[23], by which we meant an archaeological point. We accept the definition of an "entity clearly defined in space and culturally and chronologically interpretable"[24], and "off site", a much debated term in the field of "survey".

The initial phase of our project concerned the creation of an Archaeological map of the area which allowed us to document a constantly evolving situation. During the entire period of our project, the area was repeatedly subjected to large scale structural and infrastructural projects (for example, the Fiat factory on the Melfese plain, the Bradanica road, and windmill farms on the hillsides). Our work which predated these projects allowed us to document the situation before it was altered, and in some cases, like that of the Fiat factory[25], served as the archaeological risk map.

The area of Ager Lucerinus presents an ancient complex and varied landscape, and the archaeological map created offers a valuable instrument of protection in this area constantly threatened by the spread of wind farms. In fact the data processed by the GIS Laboratory of Archaeological Cartography, according to the Archaeological Superintendence, have been used for "Piano Paesaggistico Territoriale della Regione Puglia" (Puglia's Regional Landscape Plan) [26].

We were able to document situations where radical changes in the landscape had occurred due to agricultural interventions (planting of grape or olive groves which require digging deep holes and continual plowing). We were also able to contribute to actions to safeguard and protect areas of great archaeological interest.

3. Results and Discussion

3.1 The Ager Venusinus Project

The Ager Venusinus project, carried out over nearly two decades (1989-2002) coordinated by Paolo Sommella and Maria Luisa Marchi, benefited from a rich synergy of institutional and human resources. Many generations of students and scholars participated in the projects and many advanced technologies were tested (Fig. 12). Our project, for example, represents one of the first applications of both GIS (geographic information system) and GPS (global position system) in archeology. During the project we carried out an extensive and intensive survey of the ancient colony of Venusia in the Melfi district (Bottini 1982, pp. 152-160) between the Ofanto valley and the slopes of Mount Vulture (Fig. 13).

place or location where something is found. Each site is in some sense recognisable and discrete … Site implies a fixed, formal entity".

20 Di Giuseppe 2005, 8-9.

21 Livio, III, 13; III, 26; XLII, 34; V, 53.8; Plinio. N. H. 16.14;Virg. Ecl. 1.69; Col. R. R. 12.15.1; Festus s.v. tugurium.

22 Cic. Ad Att. 8.9.3; 8.13.2; 12.27; 16.6.2; Apul., Met., I.21.

23 Belvedere 1994; Manacorda 2007; Quilici, Quilici Gigli 2003, 45; Carandini et al. 2007, 13-25.

24 Plog, Plog, Wait 1978, 389-94.

25 Azzena 2001, 77-86.

26 Marchi et al. in press.

Fig. 12 Ager venusinus project, achaeological survey: the team (1990-2000).

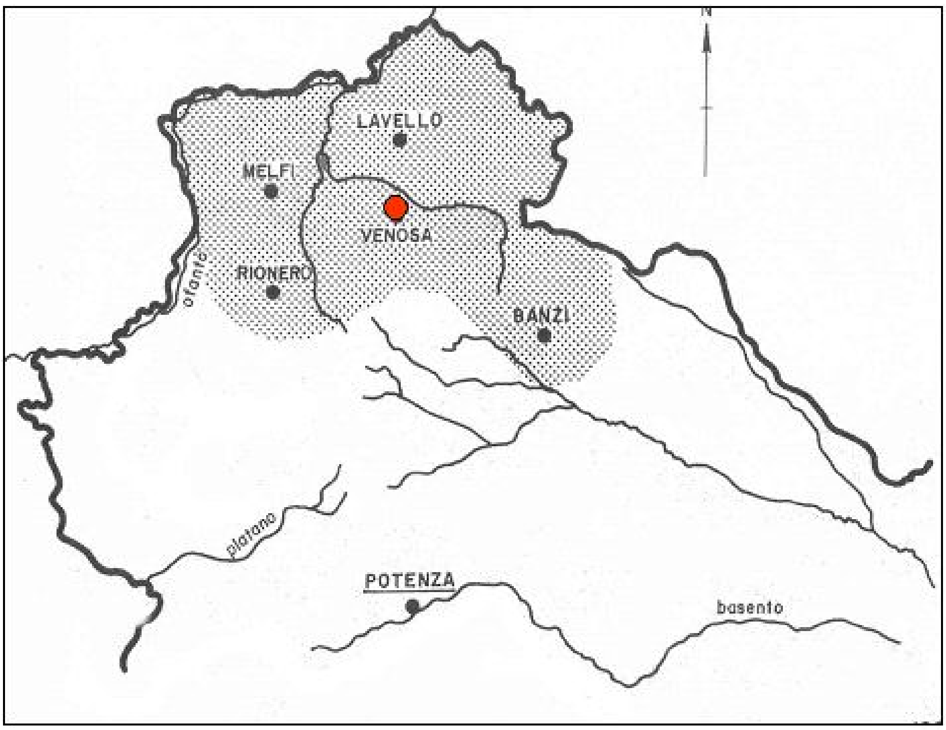

Fig. 13 The "Melfese" area.

The first volume published in the project, Venusia, contains an ample discussion of the techniques and methodologies employed, the survey and data analysis[27] (Azzena, Tascio 1996, 281-297; Azzena 2004). Other publications provide further information. Therefore, a brief summary will suffice here.

We were able to draw up a map representing an area of seven hundred square kilometers, with more than two thousand identified archaeological sites. This map helped us reconstruct the historical archeology of the ancient landscape from Prehistory to the High Middle Ages and promote the protection and cultural appreciation of the territory. The archeological survey covered all the phases of territorial occupation, according to the criteria of systematic methodology.

[27] Azzena 1992, 747-66.

This type of survey is considered more useful than one restricted to a particular chronological period.

Our research was carried out according to the scheme established for the Forma Italiae using the IGM (Istituto Geografico Militare)[28] maps 1:25,000 (187 I NO-Venosa; 187 I SE - Forenza; 188 IV NO - Palazzo S. Gervasio; 188 IV SO - Genzano di Lucania; 175 II SO - Lavello). In the field we used the Regional Technical Map (Carta Tecnica Regionale, CTR) available at a scale of 1:10,000 or 1:5,000. For some towns, but not all, digital aero photogrammetric maps are available. In many cases, it was possible to integrate orthophotos. In all cases, we used cadastral maps, which are fundamental for determining areas that should be protected, even though they contain no altimetric information and are sometimes outdated, for which reasons they are not easy to use in the field.

The first volume published in the project, Venusia[29], contains an ample discussion of the techniques and methodologies employed, the survey and data analysis [30] . Other publications provide further information. Therefore, a brief summary will suffice here.

This was one of the first archeological projects in Italy to use GIS, experimenting with database input and with GIS applications. Our project included the creation of a dedicated GIS[31]. It was also one of the first to work with GPS. Between 1989 and 1992, studies and experiments were carried out on automatic systems for the acquisition, calculation and management of archaeological data relating to the Carta Archeologica d'Italia (Forma Italiae).

Our interest in using GPS (global position system), developed in the USA for military purposes, derives from the difficulty in applying traditional systems to determine the coordinates of a point, and consequently the plan of the archeological element to which it refers that is, the difficulty in placing (or rather, georeferring) a given point in the IGM network of coordinates. The difficulty arose from the scarcity of geodetic points in the IGM maps. GPS provided the means to overcome the difficulty, allowing us to calculate the coordinates of a point using satellite systems.

By using differential systems—we used WM102 receivers—we obtained millimetric precision. It took approximately two hours to plot each location. Initially we plotted a select number of major points with the WM102 in order to integrate the IGM network and establish the starting point for identifying the topographic stations to be included in the survey. Following this experiment, we used several different types of GPS receivers, as new more precise models became available (Trimble-Pathfinder Pro XRS). Currently we use GPS for all archeological sites.

The mass of data gathered (more than 3,000 items) allowed us to refine techniques and methods for constructing a database. We experimented with many formats for entering data regarding both sites and materials.

During the entire period of our project, the area was repeatedly subjected to large scale structural and infrastructural projects (for example, the Fiat factory on the Melfese plain, the Bradanica road, and windmill farms on the hillsides). Our work which predated these projects allowed us to document the situation before it was altered, and in some cases, like that of the Fiat factory[32] , served as the archaeological risk map.

We were able to document situations where radical changes in the landscape had occurred due to agricultural interventions (planting of grape or olive groves which require digging deep holes and continual plowing). We were also able to contribute to actions to safeguard and protect areas of great archaeological interest.

In this context, I would like to mention the Casalini Sottana settlement in the town of Palazzo San

[28] The Military Geographic Institute, the national mapping agency for Italy.
[29] Marchi, Sabbatini 1996.
[30] Azzena, Tascio 1996, 281-97; Azzena 2004.
[31] Marchi, Mazzei 2012.
[32] Azzena 2001, 77-86.

Gervasio (Pz)[33]. Several years ago, there were plans to create a quarry in the area, but thanks to our survey which had revealed this rich settlement there, we were able to advise the authorities against the quarry project (Fig. 14).

This settlement occupies polylobed plateau with steep slopes, situated at the confluence of two streams covering about forty hectares. Taking into account the size and density of the site along with material found there, we were able to identify the functionality and distribution of the various housing sectors. We identified the area of the acropolis at the highest point where later, in the Middle Ages, a fortified structure arose which is still visible in an aerial photograph. Hand craft sectors characterized by kilns were also identified mainly on the basis of waste materials. The cult areas are identifiable through fragments of architectural terracotta and votive figurines. The discovery of extremely finely crafted ceramics may indicate certain areas as burial grounds.

In conclusion, thanks to the intervention of the Archaeological Superintendence to monitor the area following our report, the quarry project was not carried out. This is a fine example of how archaeological research can also contribute to conservation[34].

The ultimate goal of this long project is however the historic reconstruction of the area and the ancient landscape which captures the complexity of its variations, in the perspective of both natural and anthropized changes. In this perspective, the description of the settlement must perforce be global and refer to all the phases of occupation, from Prehistory to the Middle ages[35]. Although we based our initial research on a chronological assumption that connected it to the territory of the Latin colony and that therefore defined its dates within the Roman age, as our work progressed, our field of investigation expanded and our research took on geographic connotations.

This was one of the first archeological projects in Italy to use GIS, experimenting with database input and with GIS applications. Our project included the creation of a dedicated GIS (Carta Archeologicad' Italia: Archeological Map of Italy–Forma Italiae)[36]. It is important to keep in mind that having the entire project with all its analytical data in the GIS makes cartographic references and indications of scale superfluous. All archeological elements, both monumental and structural as well as scatter of material on the surface are georeferenced, their shapes and sizes perfectly represented.

Our project was also one of the first to work with GPS (global position system)[37]. Between 1989 and 1992, studies and experiments were carried out on automatic systems for the acquisition, calculation and management of archaeological data relating to the Forma Italiae.

3.2 The Ager Lucerinus Project

This paper also introduces the main research results regarding Luceria (Apulia), in the so-called Daunian district. In particular we focused on the western area, towards the Daunian subappennine, which includes the municipalities of Lucera, Pietramontecorvino, Motta Montecorvino, Volturino, Casalnuovo Monterotaro, Biccari, Roseto Valfortore (the entire Foltore valley), adding to the analysis of the Lucera territory already carried out by our team in the northeastern area[38] (Fig. 15).

The Ager Lucerinus project was carried out over a period of almost ten years.

The main aim of this research was to perform a complete historical reconstruction of the anthropized landscape of the Luceria colonial territory. We also included the border area between the Tavoliere and

[33] Marchi, Sabbatini 1996, 90-91; Marchi 2010, 35-39; Marchi 2014, 186.
[34] Bottini, De Siena, Marchi 2014.
[35] Marchi 2010.
[36] Marchi, Mazzei 2012.
[37] Azzena 1992, 747-76.
[38] Marchi 2008; Marchi, Buffo 2010; Marchi, Forte 2012; Marchi et al. 2014.

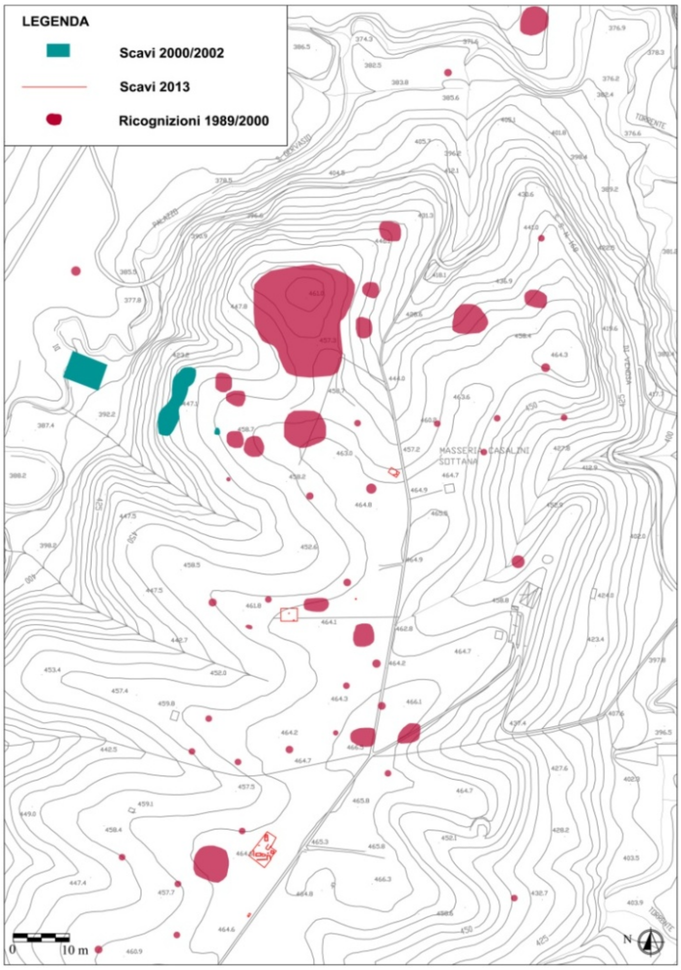

Fig. 14 Casalini Sottana settlement: archaeological map.

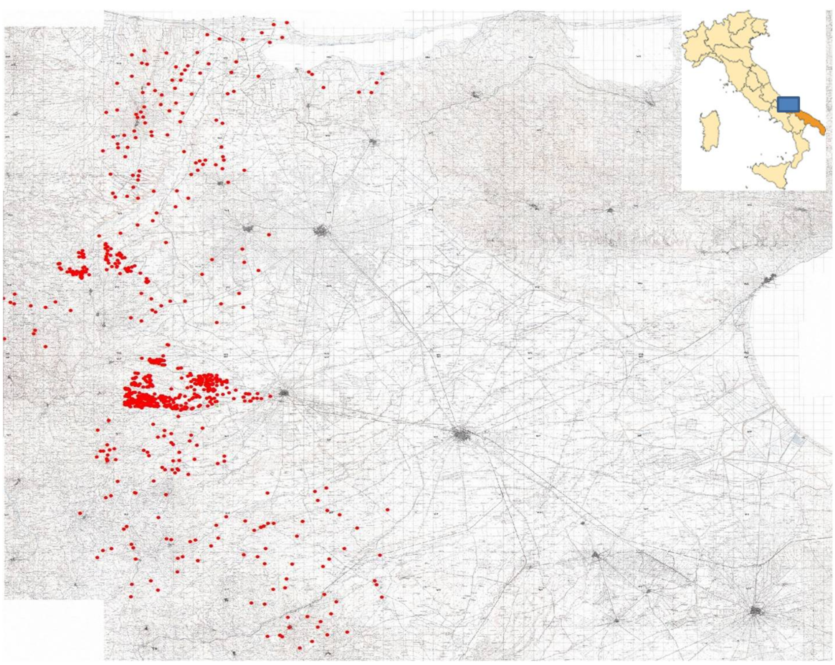

Fig. 15 The Ager Lucerinus project.

Daunian subappennine relevant in order to understand the limits between the so-called Daunian and Frentani territories, according to ancient literary sources[39].

New data, emerging from recent surveys, show the presence of a large population over the time-span from Prehistory to the High Middle Ages. We found 1,200 archaeological points.

These include Neolithic and Bronze ages settlements, located on vast plains. Traces of a huts village surrounded by the typical C shaped ditch, are visible on the northern sector of the investigated area.

According to ancient written sources, this area was under the so-called Daunian influence, between the 8th and 4th centuries B.C. Our new data seem to indicate a rather extensive human presence spread throughout the entire area (Fig. 16). One particularly notable settlement is that of Masseria Torretta and Selva Piana-Carignani, located at the center of a low plateau outlined by an abundant scatter of fragments, dated to the 5th-4th centuries. Aerial photography reveals traces of a rectangular building which might be interpreted such as an oikos.

A very interesting part of our project focused on the analysis of "Native" settlements in the period preceding the Romans' arrival and the resulting colonization of the area.

In this perspective, one of the most important case studies is the site of Chiancone, located in the nearby Lucera (Foggia Province) (Fig. 17).

The settlement, situated on a large plateau surrounded by steep slopes, covers about two hundred hectares. Like other "Daunian" settlements of the same period, Chiancone seems to be organized in alternate groups of dwellings and burials areas clusters of ceramics fragments (i.e., bricks, tiles, "Daunian" Matt-painted, Red-figure pottery, Black-gloss ware sherds) testify to the presence of a residential building, which might be dated between the 7th and the 4th century B.C. Moreover, taking into account the dimensions of the site and the density of material found on the ground surface, we might be able to identify and interpret the function and distribution of several dwelling sectors. For example, many antefixes (i.e., a relevant specimen with a "knight" similar to an antefix discovered in the votive deposit at Lucera), as well as a mold, may indicate the existence of a production center (e.g., an antefix with nimbus which bears similarities with the Etrusco-Campanian samples identified at Arpi, Teano and Lucera).

This area also yielded the tomb of a "warrior" dated to the 5th century B.C., on the base of the extraordinary grave goods. Among the thirty-five objects found, there were many ceramic vessels (i.e., an urn containing a dish, an olla, an Attic black-figure kylix, a so-called "Ionic-type" cup, datable to the final decades), defense weapons and skewers, placed nearby the feet of the deceased, who was buried in supine position (Marchi et al. 2015 in press).

The major change in the ancient landscape was undoubtedly produced by the Roman intervention and the foundation of Luceria. The planning of the new colony consequently entailed the reorganization of avast territory and the division of the adjacent rural area into a densenet work of small properties assigned to the settlers.

These transformations may be recognized, in particular, in the area of Selva Piana, where clusters of ceramics fragments allowed us to identify small buildings of 100-200 square meters and in Fornello, where aerial photography clearly displays traces of centuriation.

The farms were later replaced by early imperial villas. Medium-sized rural settlements begin to spread and polynucleated structures, that is, structures consisting of several buildings close together, sometimes incorporating previous buildings, begin to appear. The number of settlements in the early Imperial periods grew notably but is most evident in the recurring reoccupation of pre-existent structures. The medium-large villas which began to appear mark

[39] Tolomeo, Geogr., III, 1, 14; Pomponio Mela, 2, 4, 66; Pomponio Mela, 2, 4, 66; Strabone, VI, 3, 8.

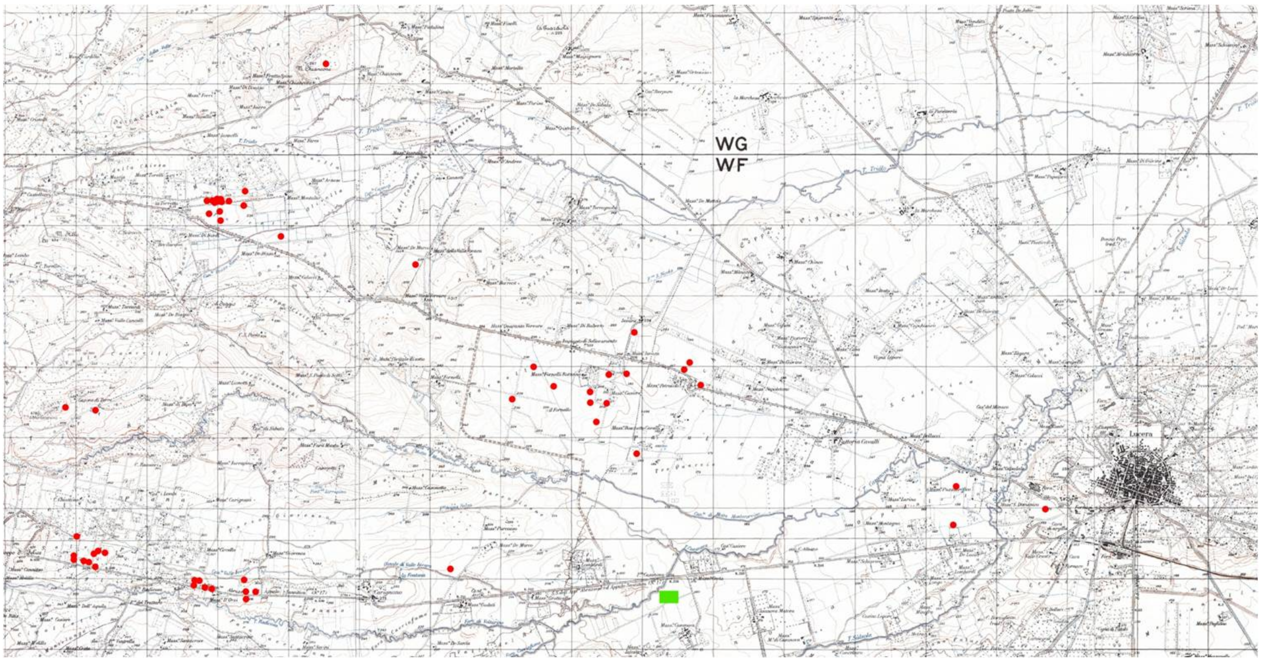

Fig. 16 The site of daunian age.

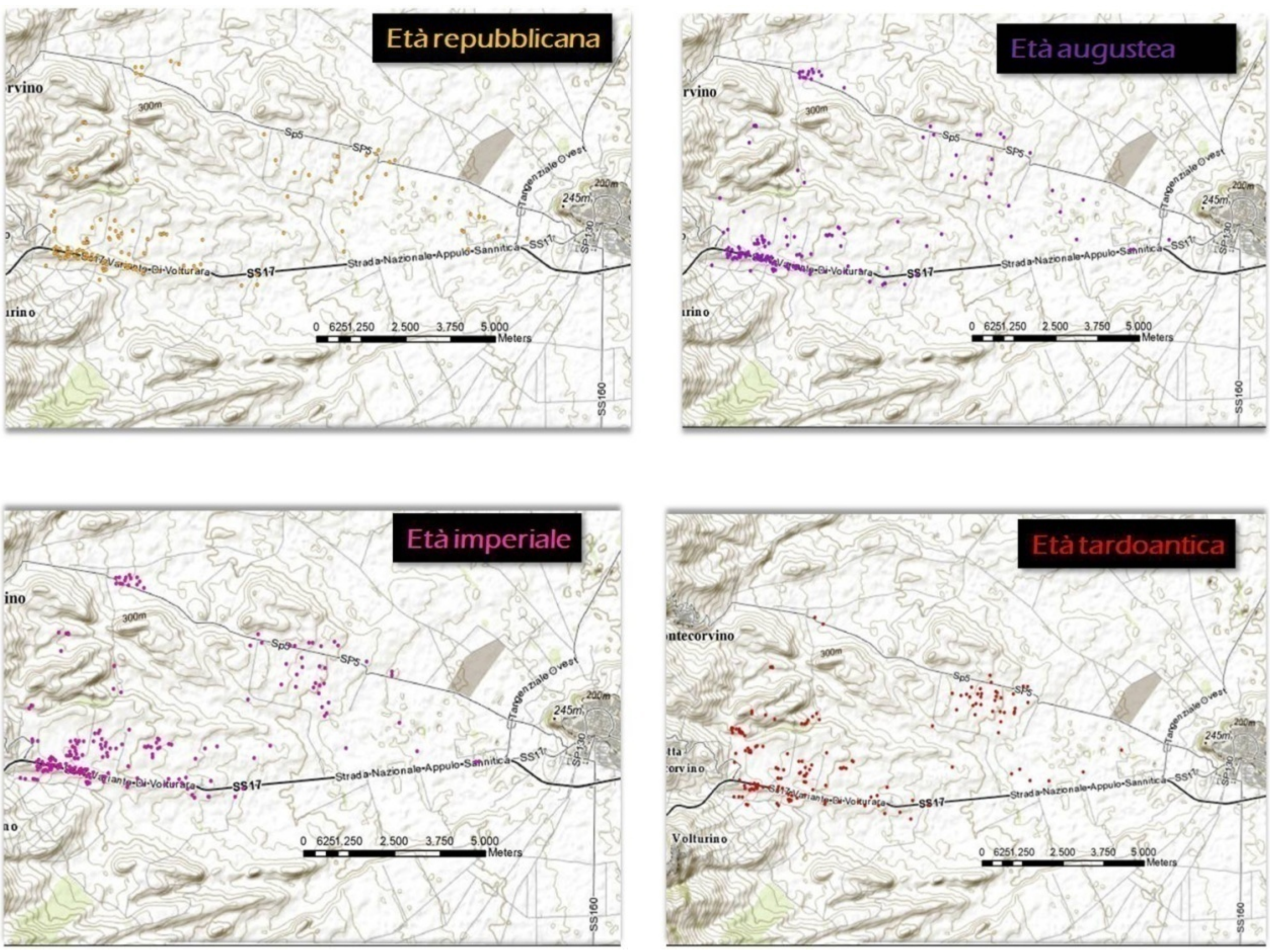

Fig. 17 The Ager Lucerinus project: age maps.

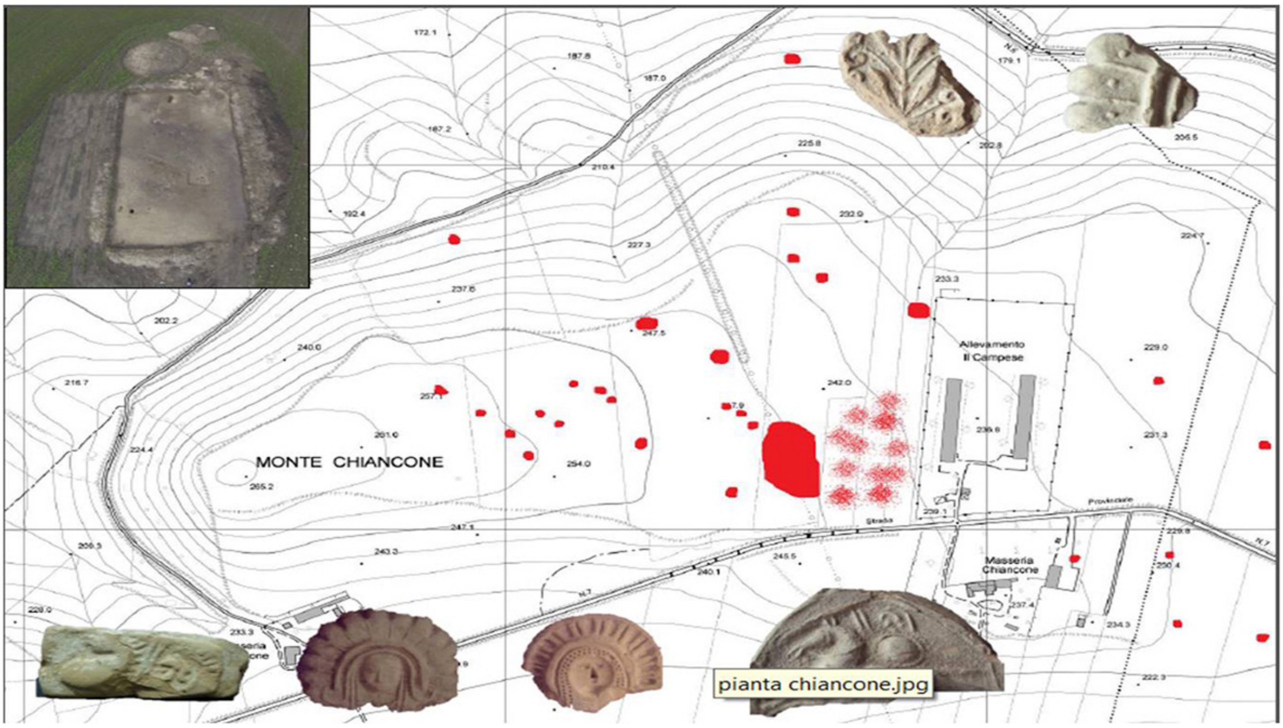

Fig. 18 The Chaincone site: Lucera (Foggia) territory.

the beginning of the process that was completed in the Mid-Imperial period with the emergence of latifundia.

The mass of data gathered (more than 3,000 items for the Ager Venusinus project and 1,200 points for the Ager Lucerinus project) allowed us to refine techniques and methods for constructing a database. We experimented with many formats for entering data regarding both sites and materials.

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