THE IMPACT OF EL NIÑO 1997/98 ON VEGETATION IN NORTHERN PERU AND ECUADOR

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Abstract

While spatial distribution of heavy rainfalls during El Niño 1991 / 92 and EN 1997 / 98 was mainly concentrated on the western coastal plains of Ecuador and northern Peru, the western part of the Amazon Basin and especially the Andes were much less influenced by equivalent phenomena. Most of the high precipitation at the pacific coast is triggered by extended land-sea breeze systems (1). In these cases the western plains are affected by sea wind fronts during daytime up to the 1.000 m contour line of the western escarpment of the Andes. Sometimes the convection which is initiated in the coastal plain and on the western Andean slopes during the afternoon, is additionally intensified by an entrainment of reminders of cirrus shields passing over from the eastern margin of the Cordillera (2). These fragments spill over the Andes by well-developed easterlies in the mid / upper troposphere which flow opposite towards the sea / up-slope breezes. Crossing points are given there, where the mean altitude of the mountain range is significantly lower, i.e. in the valley axes perpendicular the mountain chain as well as in the Andean depression in southern Ecuador. Finally, a third type of heavy rainfall is extended over wide areas during the main EN-phase in March / April, given by an extensive instability and marked by wide convective cloud complexes (3).

While the Andes are not characterised by increased precipitation and do not show major vegetation changes during EN, this is most evident for the coastal plains. In these cases open shrub and tree stands of *Prosopis pallida* and *Capparis scabrida* in the Sechura Desert in northern Peru are accompanied by dense and fast reacting annuals, medium-term surviving herbs and dwarf-shrubs, while trees show a long-term increase of growth and a strong "regeneration push". Further inland around Chulucanas tree savannas with *Acacia macracantha* and *Cordia lutea* show after EN events several ephemeral communities in addition to the perennial one:
- An ENSO-community with progressive dynamics after heavy rainfalls.
- Post-ENSO-communities following disturbances by fire due to an extraordinary fuel accumulation and with progressive dynamics in the consecutive rain season.
- Possibly a La Niña-community stimulating only a few species after cooler periods.
As an increase of Niño frequency and intensity is expected disturbances and boom effects will increase too and in consequence an invasion of spontaneously reacting exotic ruderals such as *Convolvulus arvensis* and *Tribulus terrestris* might be accelerated.

Resumen

EL IMPACTO DEL NIÑO 1997/98 POR LA VEGETACIÓN EN EL NORTE DE PERU Y EN ECUADOR

La distribución espacial de lluvias torrenciales durante El Niño 1991 / 92 y EN 1997 / 98, se concentró sobre todo en las costas del  Ecuador occidental y del nor-oeste de Peru.  Contrariamente la parte occidental de la Amazonía y especialmente los Andes, mostraron menores impactos efectuados por este fenómeno. En la costa pacífica, la alta precipitación es principalmente ocasionada por sistemas extensos de vientos tierra-mar. En este primer caso (1) la costa y los pendientes del escarpamiento occidental de los Andes hasta el nivel de 1.000 m de altura, son afectados por vientos frontales del mar durante el día.  En la tarde se inícian procesos de convección, que tal vez son intensificados de manero importante por atravesados de nubes del tipo Cirrus, los cuales cruzan los Andes después de su formación sobre la parte piemontaña oriental de la Cordillera (2). Estos fragmentos de nubes altas atraviesan los Andes con alicios bien desarollados en la troposfera media / alta en oposición contra los vientos mar-montañas. Los mismos transbordos refuerzan la convección profunda del escarpamiento occidental de los Andes después su pasajes por los ejes de valles cruzando la cadena de montañas y por la depressión andina en el sur de Ecuador. Finalmente, un tercer tipo de aguaceros (3) es distribuido por areas vastas durante la fase principal del fenómeno en Marzo / Abril y caracterizado por una inestabilidad extensa por amplios caminos de nubes convectivas.

En el caso de los Andes no se muestra ni un aumento de precipitación ni cambios esenciales en la vegetación durante EN. En las costas al contrario ambos factores son evidentes. En el caso de areas desérticas en la Sechura (norte de Peru) la vegetación abierta con arbustos de *Prosopis pallida* y *Capparis scabrida*  después del Niño 1997 /98 fue enriquecida por plantas anuales que rápidamente formaron una cobertura densa que sobrevivió a corto tiempo y matorrales que sobrevivieron un tiempo intermedio; los árboles y arbustos muestran a largo plazo un crecimiento extenso y una regeneración fuerte. Más tierra adentro, cerca de Chulucanas la vegetación del tipo sabana de arboles con *Acacia macracantha* y *Cordia lutea* indícan una variedad de comunidades efímeras aparte de la communidad arbustivo perenne:
- Comunidades ENSO con dinámica progressiva después de las lluvias.
- Comunidades post ENSO siguiendo la perturbación por incendios causados por la acumulación de combustibles. Aquellas comunidades muestran una dinamica progresiva en la estación de lluvia consecutiva.
- Posiblemente la comunidad de La Niña representada por solo pocas especies que son estimuladas por el período de frío de La Niña.

Por tanto se puede contar con un aumento de la frecuencia e intensidad de "Super-Niños", también perturbaciones y una fuerte dinámica de vegetación ocurrirán más a menudo en el futuro. Este hecho podría promover una invasión de ruderales exóticos reaccionando espontáneamente, como por ejemplo *Convolvulus arvensis* y *Tribulus terrestris*.

Introduction

After the occurrence of EN-phenomena in 1983 and 1998 the Sechura Desert and its surrounding area in northern Peru as well as in south-western Ecuador are known as areas with most severe floods and the highest positive rainfall anomalies of South America, most likely even of the world. Three precipitation maps in fig. 1 give an impression of the deviations from normal conditions, completed by diagrams of three weather stations pointing out the extremely variable hygric conditions. In the case of „Super-Niño" 1997/98 two centres of precipitation were covered by more than 4.000

mm between December and May: The primary maximum of nearly 4.500 mm was situated at Tambo Grande, a second one located at the Ecuadorian borderline contained 4.200 mm. Detailed observations in southern Ecuador and northern Peru give prove of extraordinary damages by floods, erosion, and landslides in the coastal plains between Guayaquil and Trujillo and the adjacent lower parts of the western escarpment as well as in the catchments of Rio Catamayo and Rio Macará.

In contrast, the upper part of the western Andean escarpment is characterised by minor rainfalls during the two "Super-Niños", which for example is true for the region of Huancabamba posed at the very right edge of the precipitation maps in fig. 1. Furthermore, the ratio between rainfalls during ENSO 97 / 98 and non-ENSO years gives evidence for a surprisingly restricted area of extreme rainfalls in the northern coastal plains of northern Peru (and Ecuador), while the elevated parts of the Andes as well as the central and southern pacific escarpments receive normal and even minor amounts of rainfall (fig. 2).

In the first part of the paper the triggers for downpowers in the coastal areas and for the limited precipitation in the Andes are illuminated while the second part deals with the effects of heavy rainfalls on the vegetation of north-western Peru.
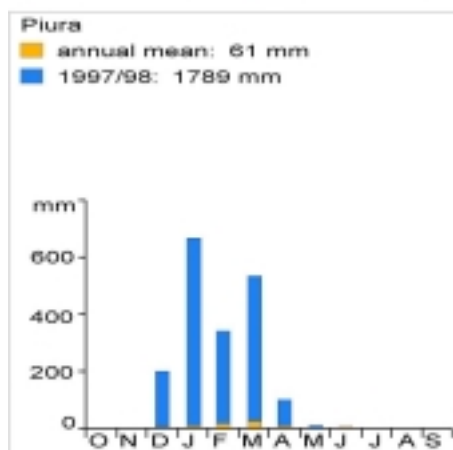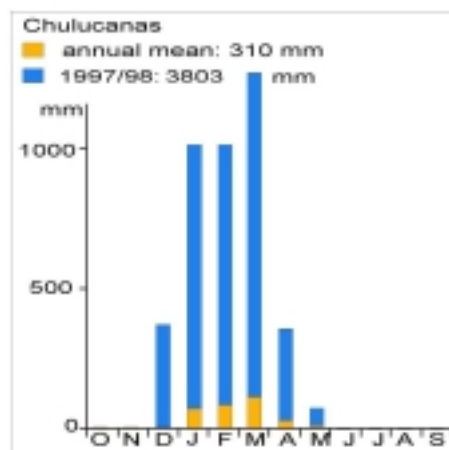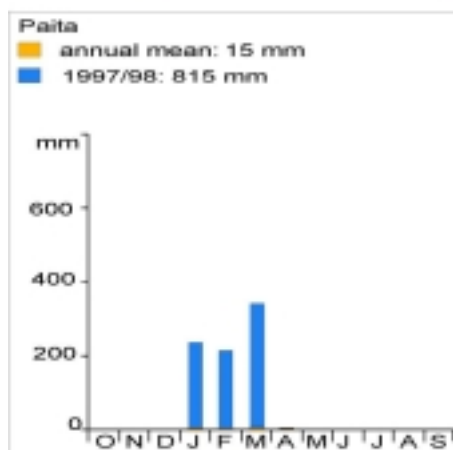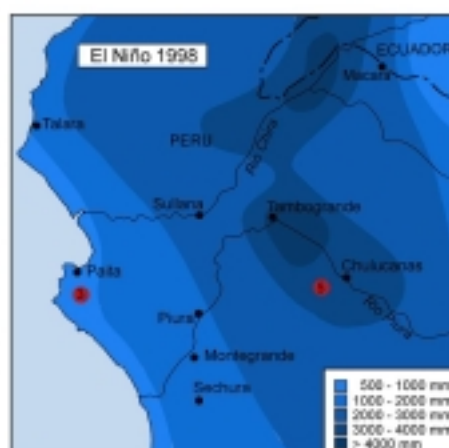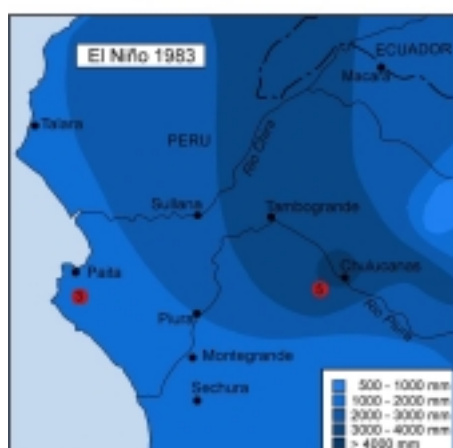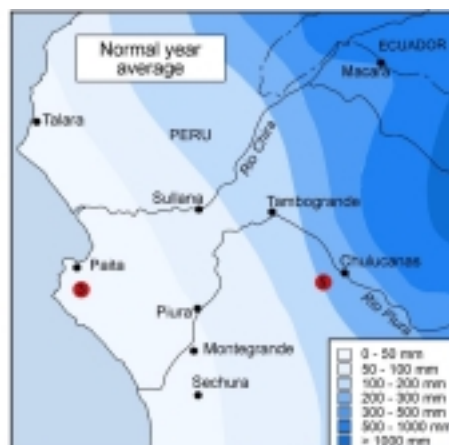
Methods

The investigation on climate genetic processes enforcing heavy rainfalls at the western escarpment of the Andes and in the coastal plains as well as the explanation for the relatively dry conditions in the Andes are mainly based on detailed numerical analyses of Meteosat-3 infrared satellite image sequences of the 1991 / 92 EN event. Control checks by the same method verify the results for the processes during the 1997 / 98 phenomenon. A major tool for the evaluation of the rain retrieval is a statistical judgement by means of the Convective-Stratiform Technique (CST) which is summarized as follows (BENDIX 2000):

- The actual relation between cloud temperature and the convective rain rate / rain area which is valid for the study area is provided by the computation of a 1D-cloud model using local radiosonde data (Galapagos, 89°37'W 0°54'S).
- A determination of exact cloud-top temperatures by Meteosat IR images in comparison with minimum local temperatures derived from NOAA-AVHRR.
- A discriminant function to separate young, intermediate, and mature storms and to distinguish between raining and non-raining Tmin pixels in the stratiform cloud area by an adaptation to the spatial resolution of Meteosat-3 VISSR.
- Extraction of cloud motion winds (CMW) by a comparative approach based on cloud movement derived from Meteosat loops.

These procedures give hints to the development of thunderstorm processes. Their itineraries, and spatial activities were performed by vegetation analyses before, during, and after EN 97 / 98 in five areas with five permanent plots (20 x 20 m) each between Paita and Chulucanas in northwestern Peru (fig. 1). In the following two representative plots of 25 in total are presented: one from the arid coast desert at Paita, the other one from the inland semi-arid tree savanna near Chulucanas. These

Fig. 1 (page 4): Position of the study sites in Northern Peru and rainfall patterns during a non-ENSO phase, the 1982/83 (both acc. to GOLDBERG et al. 1987) and the 1997/98 ENSO-event (data by Proyecto Chira y Piura); diagrams showing the monthly rainfall amounts at Paita, Piura and Chulucanas during EN 1997 / 98 (light blue) and the monthly means in non-ENSO years (dark blue).

ECUADOR
Macará
Talara
PERU
Río Chira
Sullana
Tambogrande
Paita
Chulucanas
Piura
Río Piura
Montegrande
Sechura

0 - 200 m
200 - 2000 m
> 2000 m

Normal year average

ECUADOR
Macará
Talara
PERU
Río Chira
Sullana
Tambogrande
Paita
Chulucanas
Piura
Río Piura
Montegrande
Sechura

0 - 50 mm
50 - 100 mm
100 - 200 mm
200 - 300 mm
300 - 500 mm
500 - 1000 mm
> 1000 mm

El Niño 1983

ECUADOR
Macará
Talara
PERU
Río Chira
Sullana
Tambogrande
Paita
Chulucanas
Piura
Río Piura
Montegrande
Sechura

500 - 1000 mm
1000 - 2000 mm
2000 - 3000 mm
3000 - 4000 mm
> 4000 mm

El Niño 1998

ECUADOR
Macará
Talara
PERU
Río Chira
Sullana
Tambogrande
Paita
Chulucanas
Piura
Río Piura
Montegrande
Sechura

500 - 1000 mm
1000 - 2000 mm
2000 - 3000 mm
3000 - 4000 mm
> 4000 mm

Paita
annual mean: 15 mm
1997/98: 815 mm

mm
600
400
200
0
O N D J F M A M J J A S

Chulucanas
annual mean: 310 mm
1997/98: 3803 mm

mm
1000
500
0
O N D J F M A M J J A S

Piura
annual mean: 61 mm
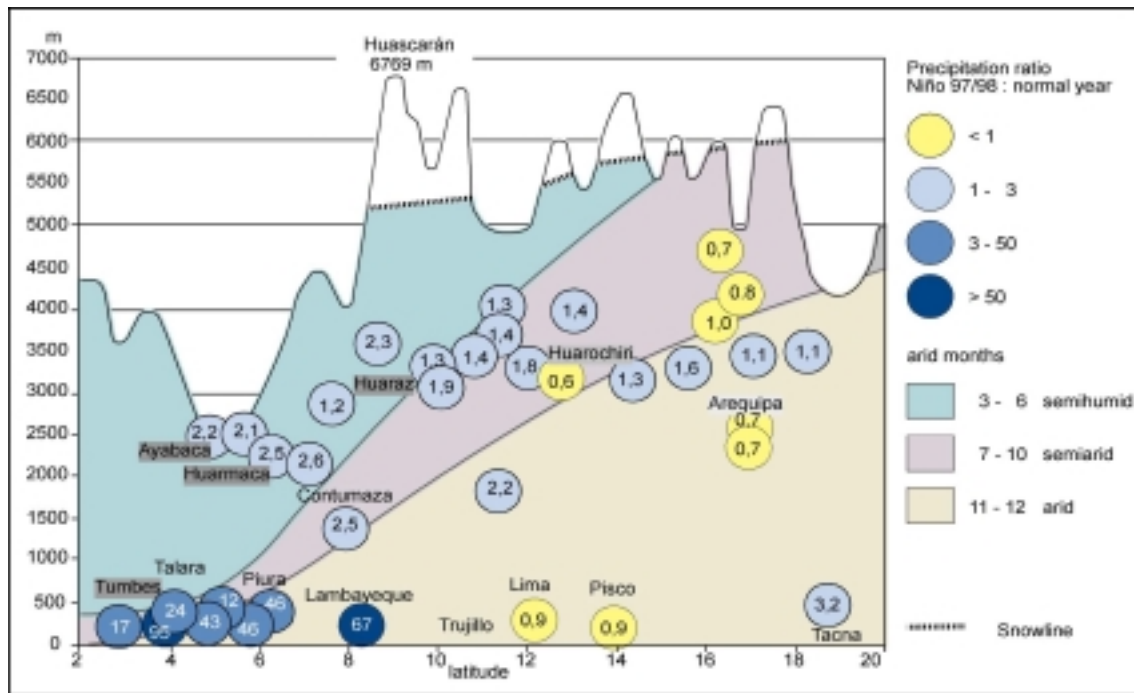1997/98: 1789 mm

mm
600
400
200
0
O N D J F M A M J J A S

Fig. 2: Amount of humid months in Peru depending on latitude and elevation (profile from north to south, after RICHTER 1996) and deviation of EN 1997/98 precipitation from non-ENSO-years (ratio ENSO 1997/98 : non-ENSO). Data source: SENAHMI.

examples cover the range from the relative driest spot during normal years (Paita = 16 mm/a 1972-82) to the most humid one during the ENSO events 1982/83 (key rainfall station: Chulucanas = 3905 mm / Jan.-May 1983). Since March 1997 all 25 plots have been visited twice a year, i.e. in March/April around the end of the rain season and in Sept./Oct., the second half of the dry period. For every sample area one of the five plots is mapped in six months intervals (fig. 3 and 4), while species releves of abundance and coverage are ascertained on all plots (s. BLOCK & RICHTER 2000). The field work is carried out over several years to enable an examination of the long term effects caused by the ENSO phenomenon; these studies are going to be continued.

Results

Spatial characterization of weather events during a typical EN-year in the further surroundings of northern Peru / Ecuador is given by BENDIX (2000):

• Precipitation maximum within the coastal plains of Ecuador and northern Peru.
• Further extensive rainfalls over the eastern Pacific north and south of Galapagos.
• Secondary rainfall maxima at the Andean slopes at the Bolivian-Peruvian border and over the Amazon Basin in north-western Brazil during the peak of EN.
• Rather normal rainfall activity in the southern part of the Northern Andes.
• Reduced precipitation within the Amazon region of Ecuador.
• No rainfalls in the Peru Desert south of 7°S.

Maximum positive rainfall anomalies during EN-events are typical for the normally semi-arid to arid coastal parts of Central and southern Ecuador as well as of northern Peru (Mantas, Guayaquil, Tumbes, Piura, Lambayaque). Within the humid area of the coastal plains and adjacent slopes in north-western Ecuador EN precipitations imply a similar intensity (Esmeralda, St. Domingo). The eastern slopes show a significant decrease in the amount of rainfall during the fenomena (Tena), while the inter-Andean
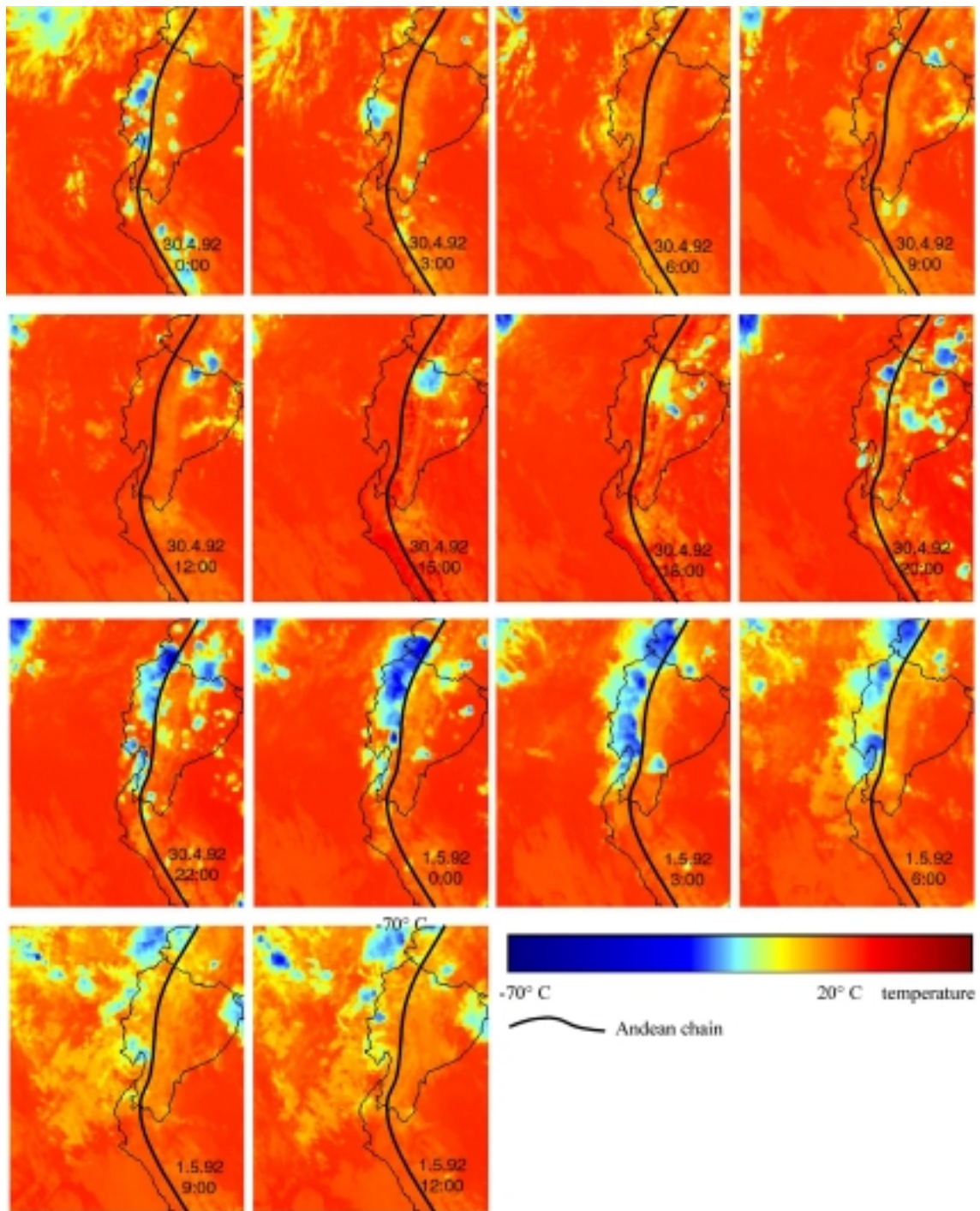
Fig. 3: Cloud motion at a 36-hours EN-event in 1992: Less extended cloud-towers close to the eastern escarpment, no or limited cloudiness over the Andes, extended cloud-towers over the pacific plain. Blue: high reaching clouds with extreme cold surfaces; yellow: cumulus mediocris clouds with surface temperatures of -20 to -10°C.

basins show moderate positive rainfall anomalies (Ambato), inputs as usual (Loja), or slight negative deviations (Huancabamba).Concerning the generic development of rainfall-enforcement a loop of cloud motion images during a typical EN-event demonstrates its minor impact on Andean environments (fig. 3). The movement of clouds leads to an interpretation of cloud motion winds (CMW) at different levels. Wind field maps of several atmospheric layers are derived for every day with heavy rainfalls

at the Nino 91 / 92-event.  The evaluation of CMWs during EN 91 / 92 enables a percentage adjustment of different mechanisms initiating heavy rainfall formations:

| | |
|---|---|
| Land-sea breeze along the coastline | 44% |
| Land-sea breeze with spill-over of the Andes | 17% |
| Extensive instability during the peak of El Niño | 39% |

These data figure out that the main area of heavy EN-downpowers is located at the coastal plains accompanied by the two mentioned areas during the peak season, but not at all in the Andes of Ecuador and northern Peru. Since the main triggers for extraordinary EN-rainfalls are obvious their main features must be pointed out.

The daily sea breeze (1) is particularly effective if anomalous wesertlies predominate in the lower troposphere. An additional intensification of deep convection is often coupled with up-slope wind systems towards the western escarpment of the Andes. At night, the land breeze takes effect particularly in releasing heavy rainfalls towards and / or over the sea with its increased sea-surface temperatures (SSTs; BENDIX et al. 2000). On the first three images in fig. 3 such late convection cells originating by the land-breeze go along with a die-off stage, indicated by blue patches near Manta and Guayaquil. These intensified land-sea breeze systems must be considered a special phenomenon since they are normally suppressed by a thermo-tidal wind which in non-ENSO years runs parallel to the coast. In ENSO years, however, the weakening of the strong thermal gradients between land and sea provides the collapse of the thermo-tidal winds. In these cases, at the end of the insolation period sea breeze-like winds with an average wind speed of 5 m s$^{-1}$ predominate on more than 50% of all days promoting deep convection and subsequent downpowers (fig.4, upper sketch).

Concerning the combination of land-sea breeze with the spill-over of clouds (2) from the eastern escarpment of the Andes, the loop between the forth and twelfth image in fig. 3 gives hints of the development and the wide enforcement of deep convection cells over the coastal plains (GOLDBERG et al. 1987). The example given for 30$^{th}$ of April 1992 shows the following sequence of circulation patterns:

- A cloud cluster, which causes heavy precipitation up to 80 mm 9 h$^{-1}$, has formed around 12:00 LT on the eastern escarpment of the Andes in southern Colombia and northern Ecuador.
- In a mature stage at 15:00 LT, it drifts with the easterlies along the Papallacta Valley axis to the Inter-Andean valley, providing only weak precipitation (1-20 mm 9 h$^{-1}$) which originates from the stratiform anvil area.
- At about  18:00 LT, the remainder of the dissipating cirrus shield reaches the western Andean slope, and at 20:00 LT deep convection develops exactly at the spill-over point, promoting severe precipitation released by several cells over the coastal plain between 22:00 and 6:00 LT (>80 mm 9 h$^{-1}$).

Further clusters can form east of the valleys of Baños and Cuenca as well as east of Loja and Huancabamba, which may be considered initial points for spill-overs, where the mean altitude of the mountain range is significantly lower. An example of spill-over effect basing on CMWs with calculated wind speeds (middle and lower sketch)  is given in fig. 4.
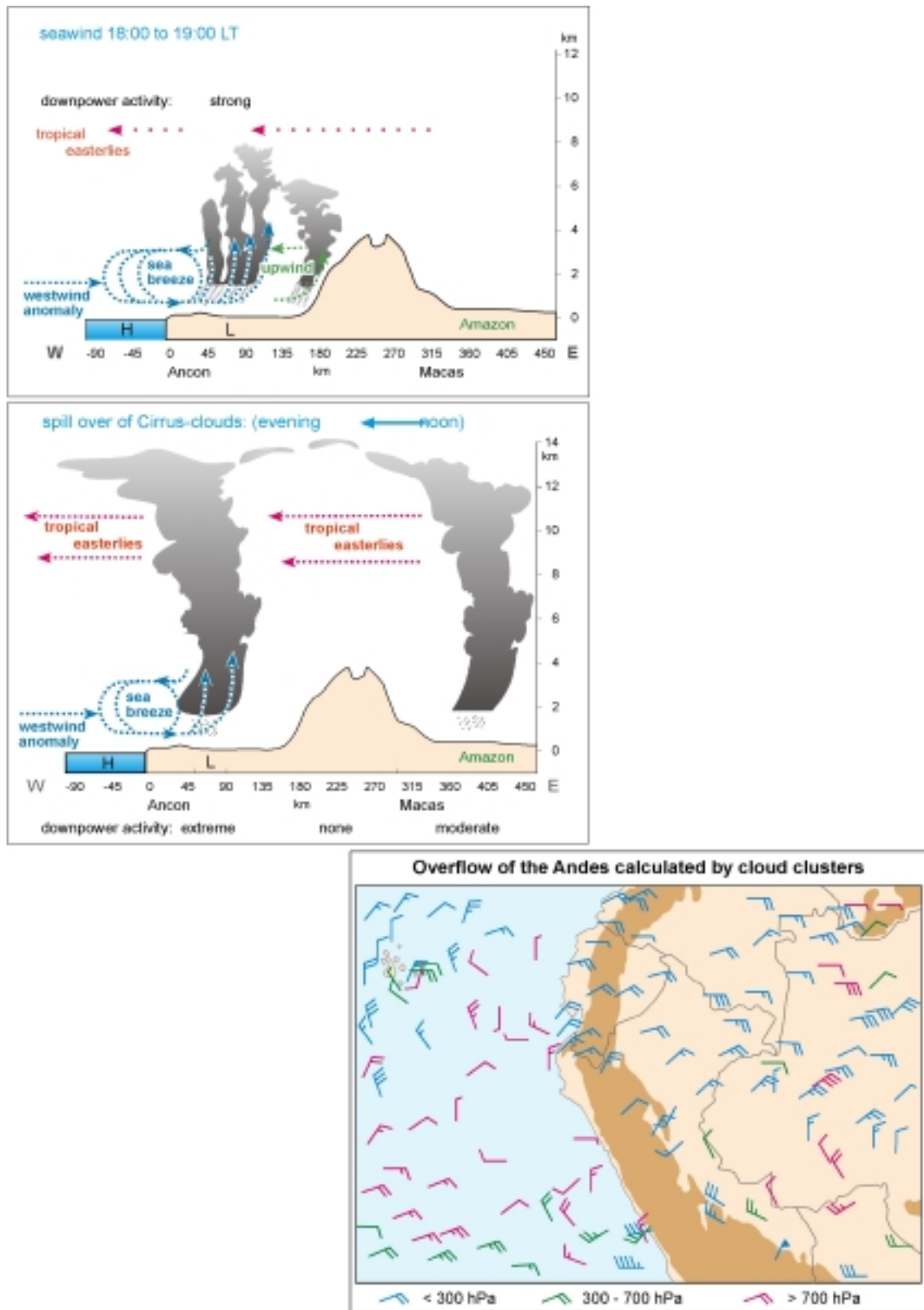
Fig. 4: Interpretation of cloud motion winds and convection cell patterns during sea-breeze (upper sketch) and strong spill-over of air masses by easterlies (middle sketch): The Andes remain relatively dry! Wind directions and wind speeds in different altitudinal levels over north-western South America derived by cloud motion analyses (lower sketch)

Land-sea breeze systems and spill-overs mostly have just local to regional effects on heavy rainfalls during EN. However, an overview interpretation of the available imagery revealed also cases of extensive precipitation in the whole north-west of the continent, particularly during the main EN-phase in March and April. In these days deep convection can be checked in several regions, sometimes organized in mesoscale convective complexes (MCC) with a spatial extension of up to 250 km and covering both marine and continental environments (3). Apart of the Sechura Desert as the central study area regions affected by the strongest downpowers are the Amazone Basin in north-western Brazil and the eastern Andean escarpment in southern Peru and northern Bolivia around the Andean bend. The main characteristic of the whole circulation form starts with an easterly upper / mid-level stream-flow crossing the Andes between equator and 5°S, then turning sse flowing parallel to the Peruvian coastline down towards the area of Lima and crossing the Andes once again south of 12°S in a opposite direction. Since this nearly closed wind field stays stable without notable diurnal alteration the extensive rainfalls at MCC events is independent of a daytime cycle and can survive for a longer period.

All three described weather situations, controlled for EN 82 / 83, 91 / 92, and confirmed at EN 97 / 98, do not lead to extensive rainfalls in the Andean mountain chain itself. The same is true for one further event of up to now minor attention, i.e. the "warm-bubble-effect" off-shore of the coastline of northern Peru and southern Ecuador. Such a situation is given rather often in the bay of Guayaquil due to the fact, that the form of the coastline is predestined for the conservation of imported warm seawater. This local sea surface warming is pointed out in Fig. 5 for March 1997 and March 1999 before and after EN 98, while the extension of a warm sea surface patch was much greater in March 2001 causing elevated rainfalls in the same month again. This monsoon affected event does not have the same genetic characteristics as El Niño and once again no major influence on the rainfall regimes in the Andes but similar effects for the coastal region of North Peru for a limited period (see rainfall-column in Piura in March 2001, fig. 5).
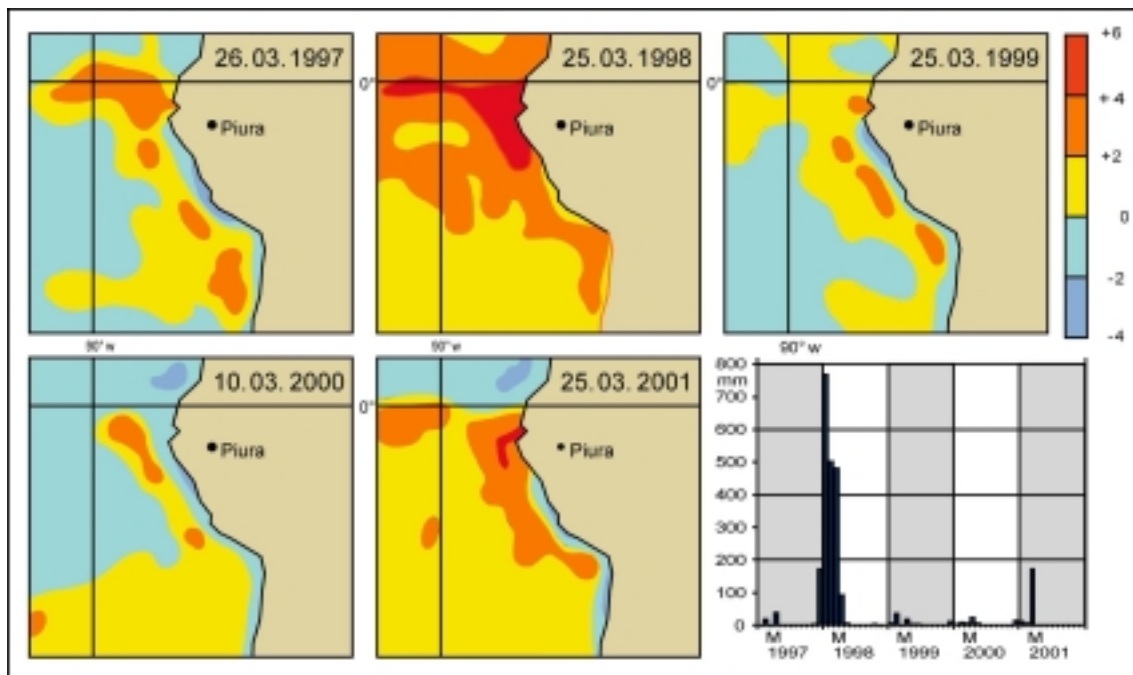


Fig. 5: Areas of elevated sea surface temperatures ("warm bubbles") due to monsoon effects in March 1997-2001 and monthly precipitation at Piura in the same period.
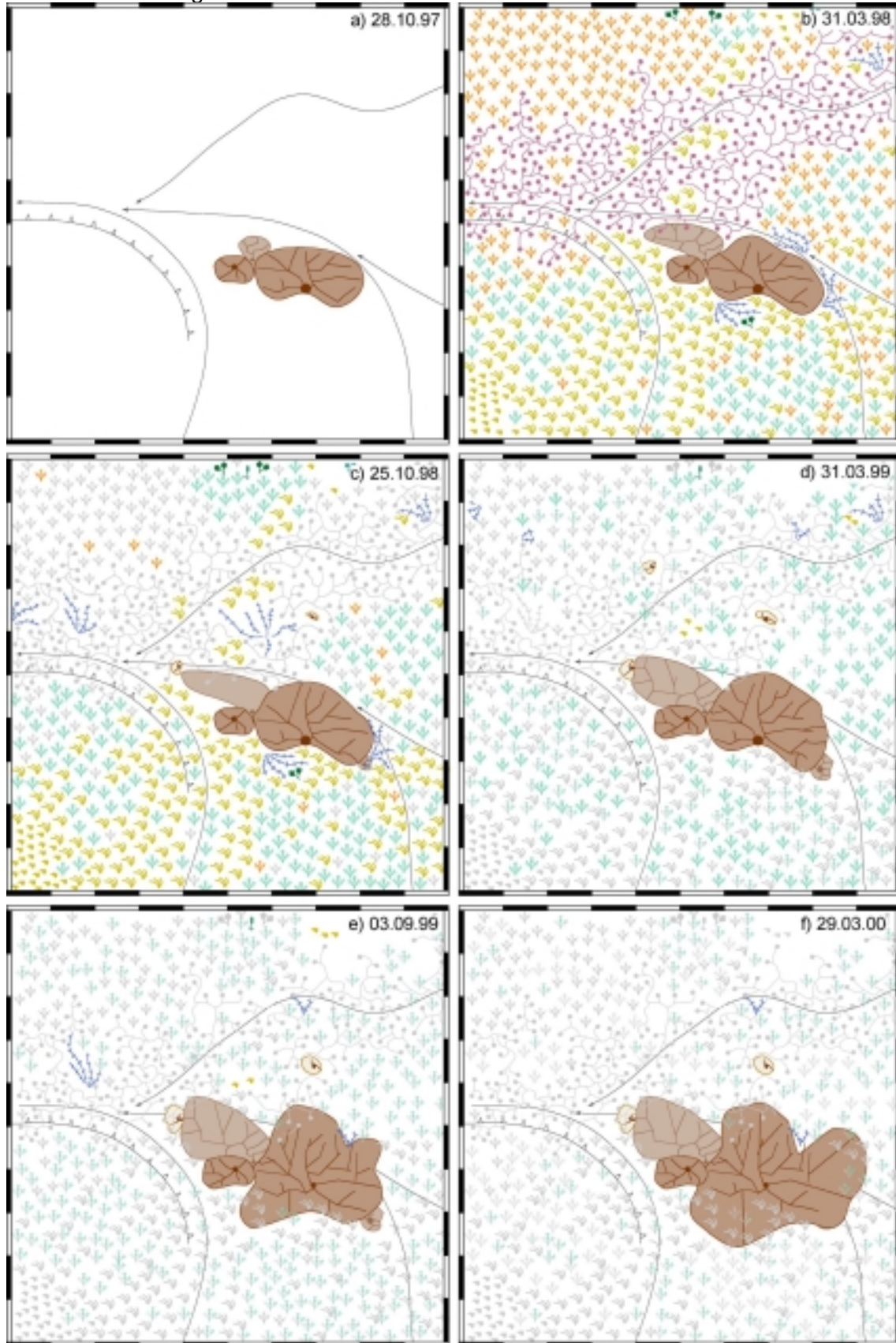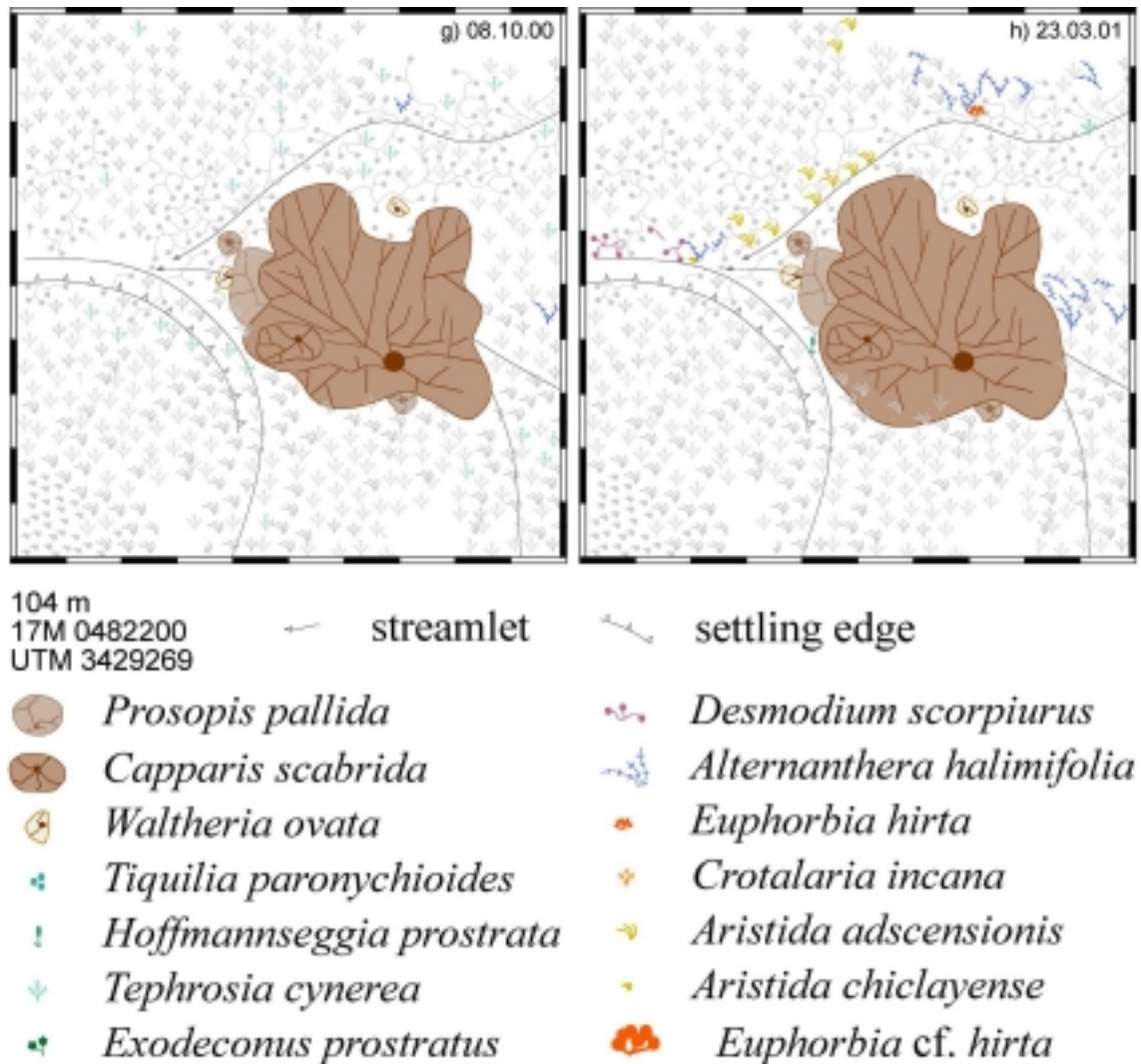
Fig. 6: Photo-sequence of plant succession at Cangrejos near Paita in northern Peru. The area is located around 200 m from the seashore and must be considered one of the most arid parts in Sechura Desert. *Capparis scabrida* in front at left, shrubby *Prosopis pallida* at right and in the background, *Aristida adscensionis* in the foreground. The location of the photos corresponds roughly with the site "sserir" in fig. 7.

How does the vegetation react on these events? Since significant vegetation changes can be assumed particularly in those regions where precipitation anomalies caused by EN are well known, appropriate investigations on fixed plots are concentrated on the Sechura Desert, i.e. the region with highest rainfall deviations. In contrast, for Andean region controls of vegetation development are restricted on regular observations of general aspects carried out in the Inter-Andean and Andean surroundings of Loja. However, by these impressions it can be concluded with best conscience that there is no evidence of extraordinary vegetation changes neither in the semihumid valleys nor in the perhumid sections of the escarpments of the Andes. Thus, vegetation changes become as more obvious as higher the climate anomalies are.

This means that a specific EN-vegetation cover characterized by the greatest deviation from a regular non-ENSO type can be observed at places which are dominated by an arid climate in regular times. The transect of vegetation plots between the coast of northern Peru gives prove of this statement since the most dramatic temporary change in species composition is to be noted at the sea shore near Paita. It becomes less pronounced at Piura or at Chulucanas and even subtle at the lower parts of the western escarpment of the Andes. This means that in a profile covering a non-ENSO precipitation gradient from 15 mm $a^{-1}$ up to 500 mm $a^{-1}$ respectively a "Super-ENSO" gradient from around 800 mm $a^{-1}$ up to 4.000 mm $a^{-1}$ and back again towards 1.500 mm $a^{-1}$ temporary vegetation changes decrease between the Pacific coast and the Andean escarpment; or, in other words: a deviation between 15 mm $a^{-1}$ during non-ENSO and 800 mm $a^{-1}$ at ENSO-events causes greater variations in plant coverage than a deviation between 300 and 4.000 mm $a^{-1}$ respectively.

Fig. 7: Successive and retrogressive development of the sserir community at Cangrejos near Paita between Oct. 1997 and April. 2001; grey signature means dead plant. This plot is situated one kilometer behind the site in Fig. 6 towards the Sierra del Diablo in the background.

104 m
17M 0482200
UTM 3429269

← streamlet

⌁ settling edge

⬤ *Prosopis pallida*

⬤ *Capparis scabrida*

*Waltheria ovata*

*Tiquilia paronychioides*

*Hoffmannseggia prostrata*

*Tephrosia cynerea*

*Exodeconus prostratus*

*Desmodium scorpiurus*

*Alternanthera halimifolia*

*Euphorbia hirta*

*Crotalaria incana*

*Aristida adscensionis*

*Aristida chiclayense*

🔶 *Euphorbia* cf. *hirta*

In the first case of Paita the ranges between a vegetation cover restricted to 8 ± 5 % of tree stands composed by a *Prosopis pallida-Capparis scabrida* community and a maximum of 100 ± 20 % composed by the same community combined with a herbal ground layer of a short-term *Aristida adscensionis-Tephrosia cynerea* community sprouting out from a seed-bank which is dormant during non-ENSO years (Fig. 7). In the second case of Chulucanas the variability ranges between a vegetation cover characterized by the above mentioned tree species completed by *Acacia macracantha* as well as by *Cordia lutea* and a herbal layer of an at least medium-term *Cenchrus pilosus-Anthephora hermaphrodita* community (Fig. 8). Independent of the ecosystem-type, tree-growth is everywhere accelerated considerably by heavy EN-rainfalls.

However, in October 1998 the Chulucanas site was affected by an extended fire fed by the immense accumulation of the straw-fuel caused by the herbal desiccation during the dry period. While the tree species recovered from the damages the occurrence of a spontaneous and vast installation of some new species in the rainy season after the event was surprising. Still absent after the ENSO-rainfalls, *Tribulus terrestris* and *Convolvulus arvensis* were prevailing now, the first one being a Mediterranean and the latter a widespread European weed. *Cyperus compressus* even showed a higher coverage expanding up to 10% in its optimum phase in April 1999. In 1999 an additional climatic anomaly was complicating the situation: single extensive rains favoured the Chulucanas area in February and April of the same year. The slight positive precipitation amount between January and May 1999 contributed to some of

the newcomers' vitality such as the therophytic native ruderals *Sida weberbaueri* and *Turnera ulmifolia*. Furthermore, also *Convolvulus* and *Tribulus* and further accompanying herbs were promoted since then.

Among these only *Convolvulus* is outlasting the winter drought in Oct. 2000 and therefore dominating in late March and even in October 2001 (not yet shown in this paper) while the other species which returned show smaller coverage. Since such fire events are not restricted on the savanna-type ecosystem but may occur in the coastal deserts too, there is evidence to classify natural ecosystems of the coastal plains in north-western Peru and south-western Ecuador as most sensitive multiple disturbance regimes (meanwhile a ground-fire touched some of the Paita-plots in May 2001; the impact will be investigated in March 2002). Taking *Convolvulus* and *Tribulus* as an example, there is evidence that in the case of EN ruderals are most efficient after events which promote plant growth according to their ability to build up extended seed-banks.

Discussion

Disturbance effects like floods in shallow hollows or river plains as well as fires on slight elevations must be considered an important compartment of ecosystem function in those regions affected by extreme climate anomalies during EN. Consequently, a future rapid change in this type of phenomenon supporting boom effects must accelerate the enrichment of its most dominant species and the input of newcomers. Whether this process of a pantropical "phytoglobalisation" (RICHTER 2001) is judged a negative aspect of EN or not is less important than the fact that destructive (floods, erosion, restricted accessibility, diseases) as well as constructive elements (water saturation, enrichment of nutrients) are combined with the phenomenon. There is prove that the highest variability in EN-effects is combined with the highest rate of climate anomaly. Since this is significantly valid for the Pacific coast of northern Peru and of southern as well as of Central Ecuador means of prevention concerning correspondent impacts should be concentrated there but less in the Andean parts of the same countries.

The last Super-Niño in 1997 / 98 marls the climax of an intensified precipitation in the research-area since the eighties of the closing century. The increase in rainfalls corresponds significantly with a more frequent warming of coastal sea surface temperatures and the resulting intensification of land-sea breezes. In case of a future increase of the SST of the eastern Pacific ("Niño 3 region"), as it is assumed by simulations based on global climate models (LATIF et al. 1997, BENDIX et al. 2000), the climate-ecological consequences for the coastal plains directly depend on the propagation of the warming trend towards the coastal waters – not towards the Andes.

Fig. 8 (p. 14 and 15): Successive and retrogressive development of the tree savanna community at Chulucanas between Oct. 1997 and April. 2001.

a) 28.10.97

b) 02.04.98

c) 24.10.98

fire!!!

d) 01.04.99

e) 04.09.99

f) 20.03.00
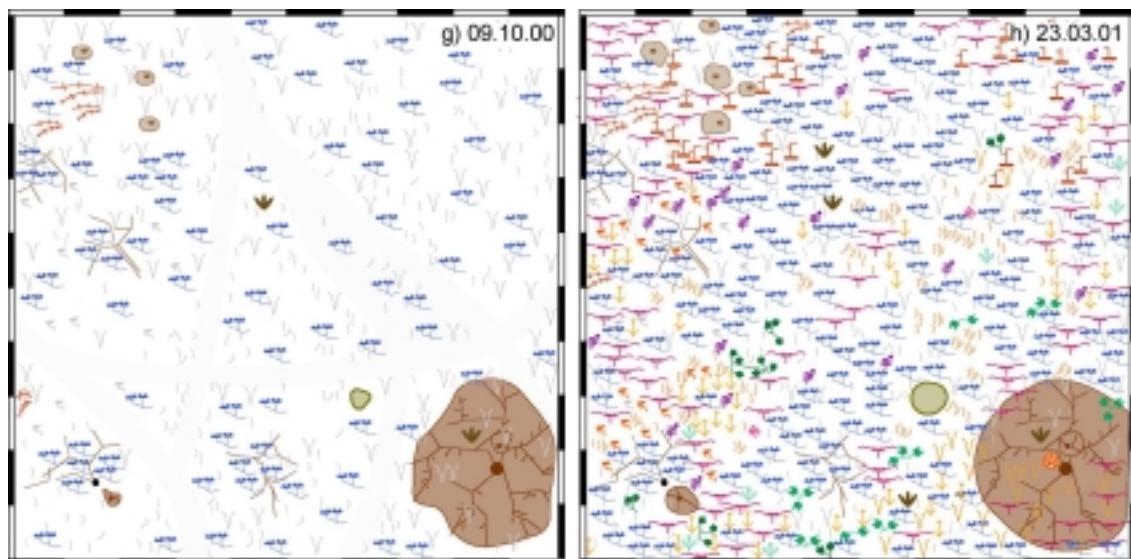
200m
17M 0576735
UTM 9432915

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|---|---|---|---|
| Prosopis pallida | | Rhynchosa minima | |
| Capparis scabrida | | Desmodium tortuosum | |
| Cordia lutea | | Asteracea spec. | |
| Acacia macracantha | | Turnera ulmifolia | |
| Encelia canescens | | Croton lobatus | |
| Aetanthus nodosus | | Boerhavia erecta | |
| Lantana scabiosiflora | | Tribulus terrestris | |
| Tephrosia cynerea | | Sida weberbaueri | |
| Proboscidea altheaefolia | | Froelichia interrupta | |
| Exodeconus prostratus | | Lycopersicon pimpinellifolium | |
| Convolvulus arvensis | | Cyperus compressus | |
| Ipomoea aegyptica | | Anthephora hermaphrodita | |
| Ipomoea tiliacea | | Cenchrus pilosus | |

branches

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