MONITORING PLANT DEVELOPMENT AFTER EL NIÑO 1997/98 IN NORTHWESTERN PERÚ

With 6 figures

MICHAEL RICHTER and MICHAELA ISE

Zusammenfassung: Dauerbeobachtung der Pflanzenentwicklung nach El Niño 1997/98 in Nordwest-Peru

Die vorliegende Arbeit beruht auf einem achtjährigen Monitoring von Daueruntersuchungsflächen in der ariden bis semiariden Küstenebene im Nordwesten Perus, welches 1997 vor dem letzten „Super"-Niño begann. Meeresoberflächentemperatur-Anomalien bestimmen die regionalen Niederschlagsmuster, die während des Ereignisses in wenigen Monaten Abweichungen von bis zu 9.000% der langjährigen Jahresmittelwerte erreichten. Neben solchen Extremereignissen treten in der Region bisher kaum beachtete Klimaanomalien auf, welche durch monsunale bzw. El Niño-ähnliche Effekte und La Niña hervorgerufen werden. Im Zentrum der Betrachtungen stehen die mittelfristigen Auswirkungen des El Niño-Phänomens auf terrestrische Ökosysteme, in diesem Fall auf die Vegetationsdynamik und ihre Konsequenzen für lokale Nahrungsketten. Ein küstennaher Wüstenstandort und ein 90 km landeinwärts gelegener Trockenbuschstandort werden verglichen. In der ersten Phase nach El Niño entwickeln sich beide Standorte in ähnlicher Weise: Kurzlebige Kräuter und Gräser bilden schnell eine dichte Vegetationsdecke. Wüste und Savanne unterscheiden sich jedoch deutlich in der fortschreitenden Sukzession bzw. der Retrogression. Hierfür sind neben den klimatischen Gegebenheiten unterschiedliche Störungsregime (Feuer und Bodenwühler) sowie eine verschiedene Landnutzungsintensität verantwortlich. Die Entwicklung der beiden Standorte ist auch im Hinblick auf funktionale Aspekte wie Lebensformen- und Habitatzugehörigkeit sowie Herkunft der Arten unterschiedlich. Die Ergebnisse werden im Kontext eines globalen Klimawandels diskutiert und auf Landnutzungsaspekte angewendet. Der momentane Trend deutet darauf hin, dass durch stärkere oder häufigere ENSO-Ereignisse neben einem Wandel in der Artenzusammensetzung zwar eine Zunahme der Phytomasse, durch gleichzeitige Übernutzung aber auch eine Degradierung der Trockenwälder hin zu Strauch-Savannen erfolgt.

Summary: This study is based on eight years (1997–2004) of vegetation monitoring on permanent test plots in the arid to semiarid coastal plain of northwestern Perú beginning prior to the last "Super"-Niño in 1997/98. Sea surface temperature anomalies control regional precipitation patterns, in some cases with surpluses 9,000% above normal. In addition to the well-documented El Niño phenomenon, less observed regional anomalies due to Niño-like monsoon effects and La Niña exist. The main focus of the paper is to present climatic impacts on the region's flora and to document the medium-term impact of El Niño on terrestrial ecosystems. We also focus on regional vegetation dynamics and consequences for the area's food chain. We compare and contrast changes at a coastal desert site and a dry woodland environment 90 km inland. Initially, both sites react similarly to El Niño: short-lived herbs and grasses sprout quickly. But the ongoing succession and retrogression differs in the desert and the woodland due to differences in precipitation at the two sites as well as differences in disturbance regimes (fire and burrowers) and in the intensity of land use. The development of life form spectra as well as spectra of habitat preferences and origin of species also differ between the two sites. Results are discussed in the context of global climate change and are applied to human land use issues where ruderals and non-indigenous species invade and change species composition. We hypothesize that increased ENSO frequency and intensity create greater phytomass that in turn encourages farmers to graze more cattle which leads to degradation with a shift from dry forest to shrub savanna.

1 *Introduction:*
Taking northwestern Perú as a core region of ENSO

This study examines ecosystem dynamics after El Niño events in northwestern Perú. To date, a thorough physiological or ecological understanding of El Niño (EN) as the driving force for successive and retrogressive vegetation change is minimal. The Sechura Desert is the central "wet spot" of El Niño Southern Oscillation (ENSO) activity, thus earlier research concentrated on the destructive effects of heavy rain, but pertinent ecosystem responses have not been documented.

The Sechura Desert and the adjacent dry forest zone of the coastal plain in northwestern Perú (Fig. 1) have episodic severe flood events and extreme positive rainfall anomalies. Due to ENSO, the study area is marked by the highest variability in annual precipitation in South America and likely even on earth (CAVIEDES 1998; GOLDBERG et al. 1987). During so-called "Super-Niños" the deviation from average precipitation in non-ENSO years may surpass 9,000%, such as observed at Talara, Perú in 1997/98.

The original aim of the study was to document plant succession and retrogression during and after El Niño

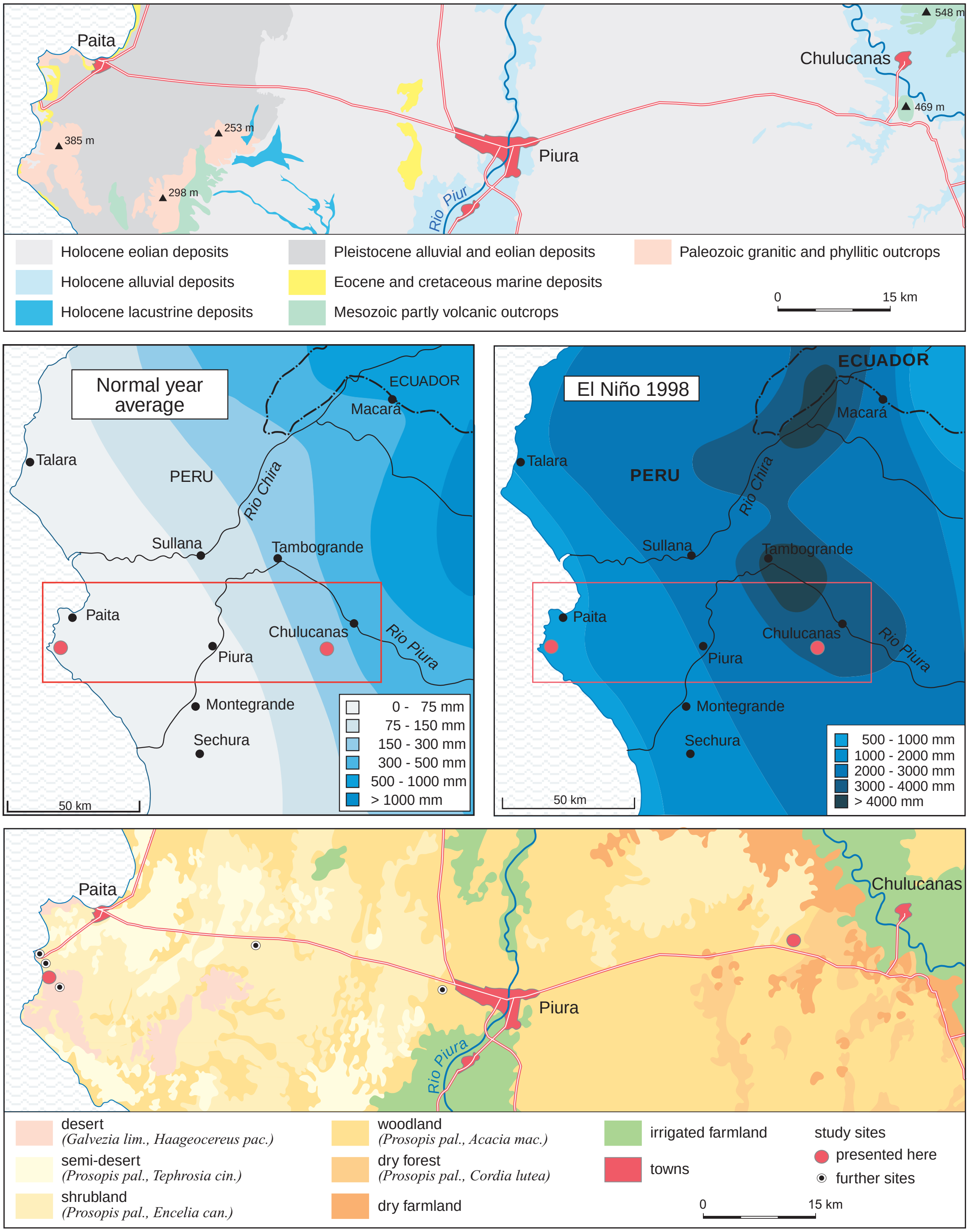


Fig. 1: Geological units in northwestern Peru (above, based on maps of INGEMMET 1984–1989), rainfall patterns during a non-ENSO year and in 1998 (centre, based on data from Proyecto Chira y Piura), and distribution of vegetation communities (below, based on maps of INRENA 1998, 2000, and on own observations)

Geologische Einheiten in Nordwest-Peru (oben, nach Karten von INGEMMET 1984–1989), Niederschlagsverteilung in einem Nicht-ENSO-Jahr und 1998 (Mitte, nach Daten des Proyecto Chira y Piura) und Verteilung der Pflanzengemeinschaften (unten, nach Karten von INRENA 1998, 2000 sowie eigenen Erhebungen)

1997/98, thus seven field sites were chosen crossing the coastal plain along a transect between the coast of Paita and the hinterland near Chulucanas (Fig. 1). This research began with the simple assumption of a rapid increase followed by a decrease of plant cover and species numbers, but the actual development was much more complex and exciting than expected. In fact, several unforeseen trends became obvious, necessitating long-term monitoring, and field observation has thus continued for more than seven years, i.e., from the pre-Niño phase in October 1997 through April 2004. Our previous results (BLOCK a. RICHTER 2000) were combined with ideas of a higher frequency or intensity of El Niño discussed in the context of climate change (BENDIX et al. 2000), which raises questions regarding future ecological development in the region.

Previous El Niño botanical research largely addressed destructive effects, such as the impact of fire or of extraordinary water surpluses within affected dry areas: for example, the extreme ENSO event in 1982/83 caused cohort mortality of the widespread *Scalesia pedunculata* on the Galapagos Islands (LAWESSON 1988; ITOW a. MUELLER-DOMBOIS 1988). LUONG and TORO (1985) and HAMANN (1985) presented species lists from the same islands before and after the 1982/83 phenomenon: effects recorded were minor changes in floristic composition with more pronounced structural changes. A large mobilization of the seed bank of non-woody species was apparent and hence, grasses, sedges, herbs, and vines proliferated, compared to previous non-ENSO years. Similar reactions during El Niño 1997/98 were reported from northwestern Mexico (POLIS et al. 1997) and northwestern Perú (BLOCK a. RICHTER 2000; GUSHIKEN et al. 2001). CÁRDENAS et al. (2001) described micro-successions of the herbaceous stratum during the six months event, pointing out the short-term change of phenological stages of most prominent species. In contrast to the given ENSO conditions in northwestern Perú, the central and southern coasts of the country, as well as coastal northern Chile, receive less rain during ENSO events (MUÑOZ-SCHICK et al. 2001). Instead, the existing herbaceous vegetation ("loma") benefits from longer lasting and thicker fogs ("garúa" and "camanchaca"), once again fostering a diverse and dense plant cover of mainly ephemerals (CANO et al. 1999; DILLON a. RUNDEL 1990; GUTIÉRREZ et al. 2000). Until recently, "boost effects" of plant growth following El Niño were rarely described although they are very important in northern Perú. WEBERBAUER (1911, 149) reported drought periods in the region which lasted five to twelve years and were interrupted by short but very effective summer rains. His notes, based on BALL's (1886) observations near Paita in 1882, mention that herbs are rare or absent in the coastal area during dry periods. This is confirmed in our research.

The study area is located on the coastal plain in a flat environment lower than 200 m a.s.l. It includes several granitic and phyllitic outcrops up to 385 m a.s.l. but is predominantly made up of Pleistocene alluvial deposits and Holocene fossil sand dunes (Fig. 1). In this paper, two sites are examined in detail, one a desert ecosystem (near the coast), the other a dry woodland (inland). We find these sites most typical of the 90 km transect between Paita and Chulucanas (with a total of 7 investigated sites, Fig. 1).

Both study sites experienced an enormous rainfall input during El Niño 1997/98 (Fig. 1). The non-ENSO average precipitation between Paita and Chulucanas lies between 15 mm/yr in the west and 320 mm/yr in the east. During the last "Super-ENSO" the precipitation gradient ran from around 800 mm/yr up to 4,000 mm/yr. Usually these high intensity events occur over a limited time period, between December and May (as observed during the 1997/98 event). Compared to this extraordinary rainfall, the temperature deviations are less well known. In 1998 temperature increased around 1.5°K during the main El Niño period (January-April), while mean wind speed decreased significantly and relative humidity in daytime was up to 20% higher than usual, as recorded in Piura (UDEP 1999). Thus, during these episodes, El Niño must be considered not only as an extraordinary change in the weather but as a special regional climatic regime, i.e. as a semi-humid rather than arid ecosystem. This means that floristic elements of another vegetation-zone should be capable of entering and establishing in the desert environment for limited periods and suggests that a fifty-fold increase in precipitation – as was the case in Paita – should cause greater variations in plant cover than the twelve-fold increase that occured in Chulucanas.

Under normal conditions the regional plant formations reflect a gradient between a tropical desert and dry forest. The only remarkable difference is the relatively high abundance of scattered trees giving the hyperarid coastal zone a slightly distinct appearance. However, detailed vegetation maps derived by INRENA (1998, 2000) from remote sensing analyses show a patchwork of different communities. Figure 1 indicates patterns influenced by varying climatic, hydro-geological, and human impacts. In the areas little changed by people, a general feature of all plant formations is the constant presence of *Prosopis pallida* ("algarrobo") and of *Capparis scabrida* (syn. *C. angulata*, "zapote"). The vegetation units of the region during non-ENSO years include:

– Desert: restricted to Paleozoic outcrops rising from the coastal plains. It is characterized by a plant cover of < 5% on stony ground (hamada) with *Galvezia limensis, Encelia canescens, Alternanthera halimifolia, Maytenus octogona* and *Haageocereus pacalaensis* as prominent members and *Prosopis pallida* and *Capparis scabrida* as sporadic associates.

– Semi-desert: concentrated on Tertiary sediments in the arid parts near to the coast. Plant cover lies between 5 and 25% on fragmented pediments or coastal terraces and contains scattered tree populations (1–5%) of *Prosopis pallida, Capparis scabrida* and *C. avicennifolia* (syn. *C. ovalifolia*), shrubs of *Encelia canescens* and prostrate subshrubs of *Tiquilia paronychioides*.

– Shrubland and woodland: widely scattered on Quaternary mostly aeolian sediments on the semi-arid portion of the coastal plain. Varying plant cover from 25 to 50% includes tree stands of 5 to 25% with *Prosopis pallida* and *Capparis scabrida*, shrubs of *Acacia macracantha* and periodic occurrence of the grasses *Anthephora hermaphrodita* and *Cenchrus pilosus*.

– Dry forest: restricted to a narrow zone on Quarternary sediments and Mesozoic stony outcrops. Plant cover on the more or less hilly terrain reaches 50 to 70% with abundant *Prosopis pallida, Acacia huarango, Capparis cordata, C. scabrida* and *Cercidium praecox*, accompanied by smaller trees and bushes such as *Acacia macracantha, Cordia lutea* and *Parkinsonia aculeata*. In rocky environments candelabrous cacti of *Armatocereus cartwrightianus, Neoraimondia arequipensis* and *Haageocereus versicolor* occur.

2 Methods

We present here two study sites that are situated at the two extreme positions of this climatic and vegetation gradient (Fig. 1). Each study site comprises five sample plots of 400 m^2 each (20 x 20 m). Since October 1997 field investigations occur twice a year in March/April and September/October, i.e. at the end of the wet season (if one exists) and during the second half of the 9- to 11-month long dry season. The coastal study site (Paita) is located 800 to 1,000 m from the coastline on a sandy plain at 65 m a.s.l. It sits on a pediment that descends coastward from the foothills of the Cerros del Diablo southeast of Paita. Aeolian processes have caused a residual concentration of gravel on the slightly encrusted surface ("eluvial serir"). Under the topsoil lies a loosely packed sand stratum. The second study site (Chulucanas) is located at 175 m a.s.l. in a fossil sand dune area covered by shrubland and open woodland. While human impact at the Paita site is negligible, goats, and to a minor extent brahma-cattle, cause continuous grazing pressure at Chulucanas.

The sample plots are situated along a N-S-transect at a 20 m interval. Regardless of the plant formation type, plot size is held constant. During each field visit, plant distribution is mapped at one plot at each site. At all plots species composition, abundance and percentage coverage as well as the degree of vitality are taken; life-form for each species is derived from visual inspection while data on habitat-preferences are based on Brako and Zarucchi (1993) and on Sagástegui Alva and Leiva Gonzales (1993).

Statistical analysis includes the calculation of mean species coverage at each site and the mean sum of coverage for life forms, habitat preferences and origin of species. Moreover, an analysis of temporal similarity has been applied using root-transformed values of mean species coverage. Similarity is calculated with the Euclidean distance measure, and clustered by Ward's method.

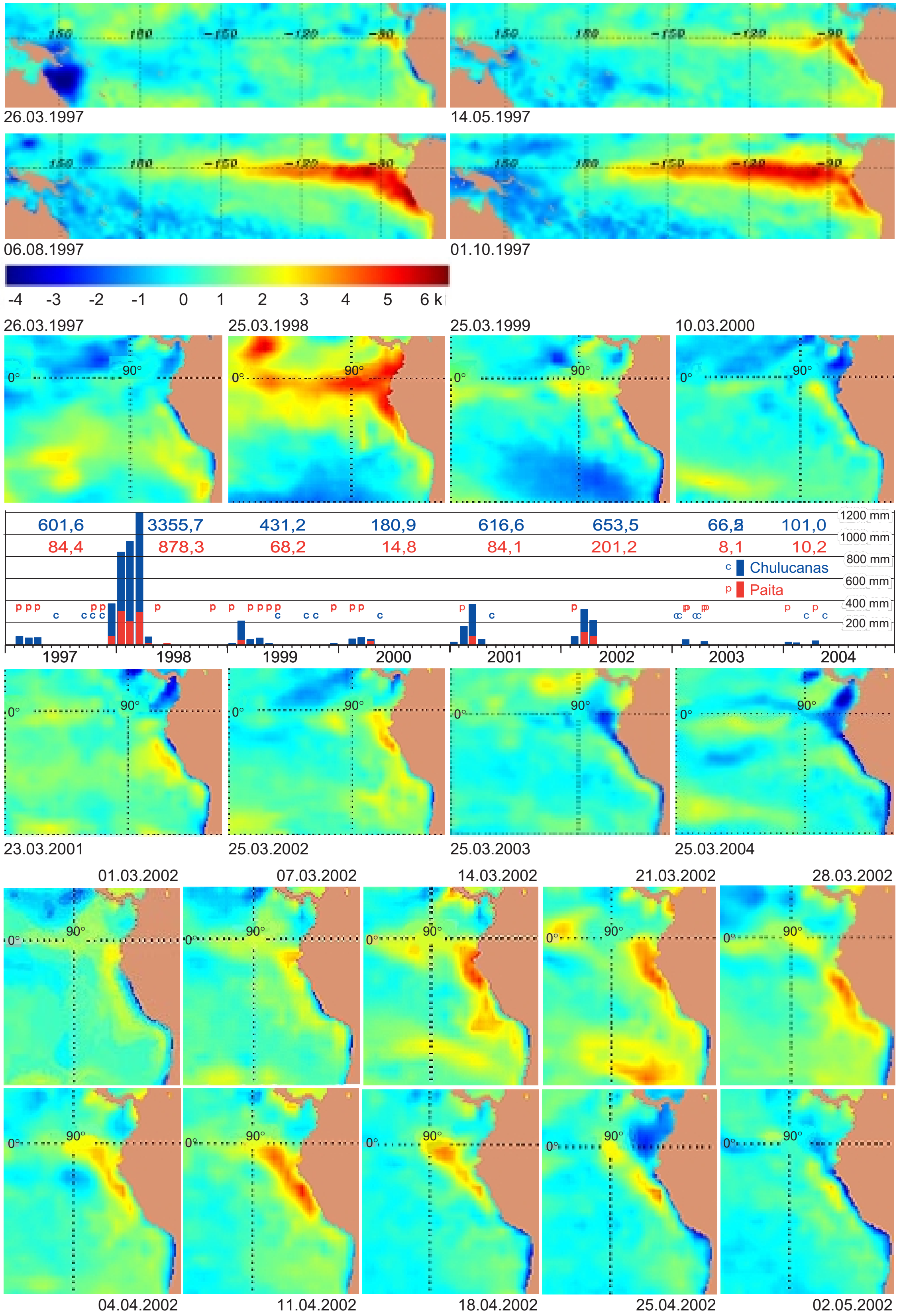
3 Results and discussion

3.1 Climatic conditions before, during, and after El Niño 1997/98

The climate conditions in the research area are connected with sea surface temperatures (SST) in the El Niño regions 1–4 (cf. El Niño Regions 2002). While regions 1 and 2 (0–10°S, 80–90°W) are only responsible for regional and local weather conditions, regions 3 and 4 (5°N–5°S, 160°E–90°W) have a global impact. These phenomena are shown in detail in figure 2, which contains three different scales in space and time of SST anomalies.

The upper four sketches of figure 2 show the advancing warm section of the pre-Niño phase; in March 1997 the anomaly had not yet developed, but over the next seven months it became obvious: torrential rainfall began in the region in October 1997, causing flash floods on the Galapagos and north of the study area around Guayaquil. Our field research area was first affected in December 1997, with Chulucanas that received 376 mm of rain.

The centre of figure 2 shows monthly rainfall amounts from 1997 through August 2004 and compares SST anomalies each March, i.e., during the wettest periods. Note the precipitation in early 1998 as a result of 1997 warming. In addition, small warm water anomalies occurred near Paita during March 2001 and 2002. This warming can be explained by monsoons that were described by Bendix and Lauer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02.05.2002

(1992): NE-trade winds cross the equator, turn SE and push warm surface water from the equatorial Niño Current towards the coast. While the Gulf of Guayaquil regularly receives warm water inputs, these monsoon effects were magnified in 2001 and 2002. Though no further OTIS SST-data is available for March 2001, we assume that the nearby coast experienced a notable warming like 2002. The SST anomalies due to monsoon effects are regional phenomena, distinct from the larger El Niño phenomenon, which are dominated by different, oceanic and atmospheric flows. They can last two months, as shown in the lower part of figure 2.

Among the rainfalls in March-April 2001 and 2002 at least the latter phenomenon is reported as a weak to moderate El Niño event (Takahashi 2004). However, NCEP re-analysis plots indicate at the 1,000 hPa-level several phases of monsoonal airflows from N and NW towards the northern coast of Perú between February 15 and 28 (cf. NOAA-CIRES). During this initial period an extended spot of warm water shifted south from the Gulf of Panamá by the Niño Current (ca. 1K warmer than normal, cf. OTIS). After 1st March 2002, i.e. the starting point of first rainfalls up to 45 mm d^{-1} in the Piura hinterland around Chulucanas and Tambogrande, the warm water vesicle was stabilized near Paita. Downpours with maximum amounts between 75 and 115 mm d^{-1} were registered three times between March 20 and April 8 resulting from a phase of enhanced SST warming of +3K between March 10 and 20.

Later, a slight general warming starting around March 25 all over the coastal section south to central Chile becomes obvious when interpreting SSTs. This event took place rather abruptly and was not connected with the antecedent monsoonal effect in northern Perú. Instead, a diminished upwelling of cold water alongside the central Peruvian to the central Chilean coast is noted but without a notable weakening of equatorward trade winds, which are considered upwelling-favourable alongshore air flows (Blanco et al. 2001). Nevertheless, this process might more likely be considered a Niño-like phenomenon than the described monsoon as an initial trigger for the sea surface warming near Paita. Whether the March-April 2002 phenomenon was a true El Niño remains a matter of discussion: While the Cold Tongue Index (CTI) which expresses the intensity of cool SSTs within a narrow latitudinal band centred on the equator in the central and eastern Pacific basin suggests an ENSO event (cf. CTI SST anomaly data), SST anomalies at Puerto Chicama as another useful EN-index do not support this interpretation (cf. Chicama Index data). Interestingly, McPhaden (2004, 680) states that an "… oceanic response to a strong December 2001 westerly wind burst was short-lived and that conditions returned to near-normal across the basin in April 2002". Instead, he reports on an El Niño which peaked in the fourth quarter of 2002. However, this situation had no rainfall consequences in northwestern Perú since SST anomalies were relatively weak along the west coast of South America.

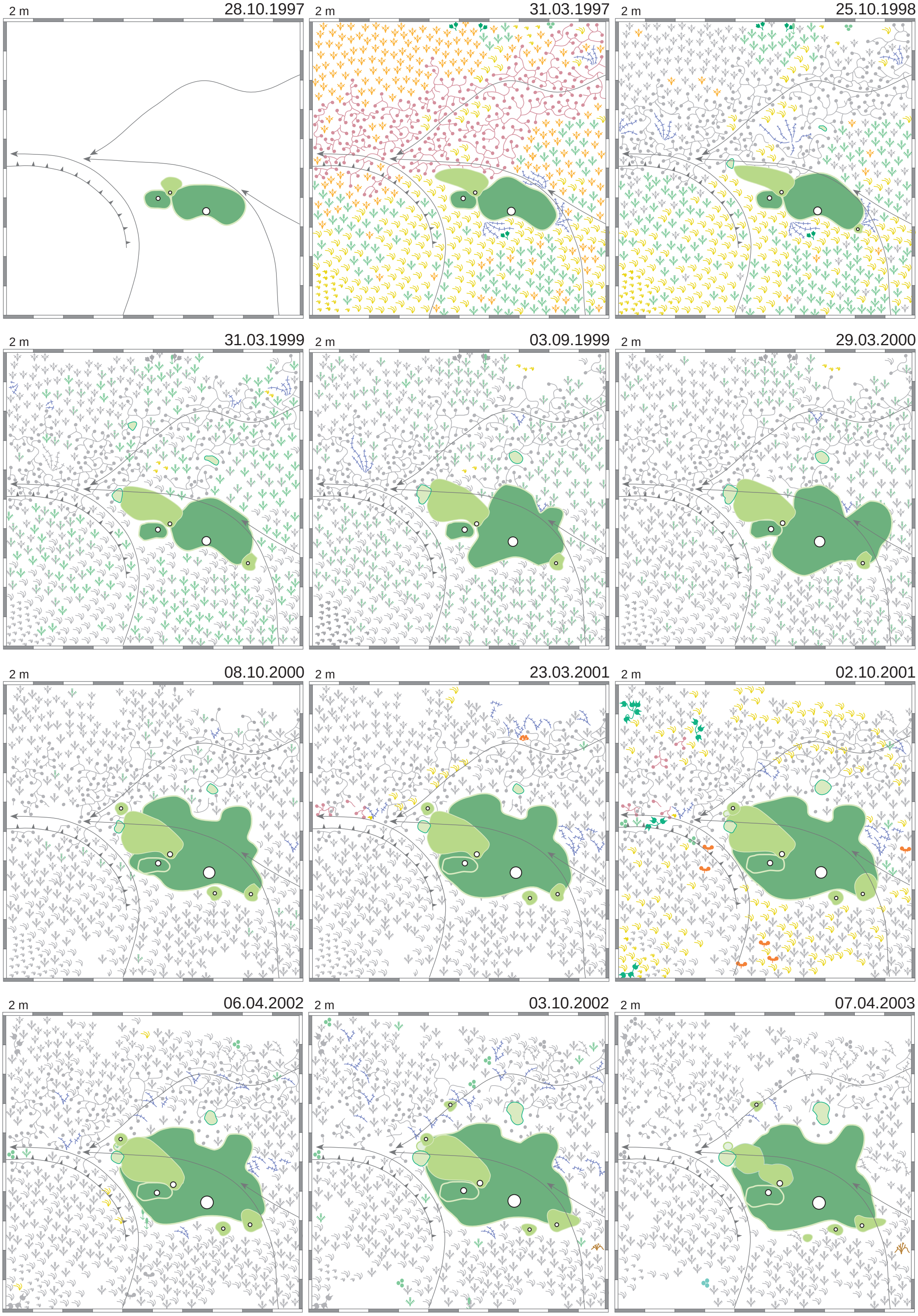
An additional climatic anomaly that affected our research area is La Niña. It typically occurs after El Niño events. In northwestern Perú it is characterized by slightly increased precipitation rates during the rainy season and by slightly reduced temperatures during the winter. Between July and September 1999 we observed mornings with garúa fogs and drizzle, normally completely absent at this latitude.

3.2 *Succession and retrogression: desert and dry woodland environments*

Given the increased precipitation from El Niño and regional monsoon effects and decreased ET from La Niña, we observed vivid ecosystem change. The moisture from Niño events stimulated a massive germination of seeds, leading to a large blooming followed by replenishment of seed banks for annual and perennial plants (Dillon a. Rundel 1990). As these reactions are

Fig. 2: Sea surface temperature (SST) anomalies during the pre-Niño and El Niño phase within the El Niño regions 1 to 4 (above), during the pre- to post-Niño years (1997–2004) within the EN regions 1 to 3 with diagram of monthly rainfall amounts in Paita and Chulucanas (the letters p and c sign rainfall amounts below 10 mm/month for Paita and Chulucanas respectively) (centre), and during pronounced rainfall events in March and April 2002 within the EN regions 1 and 2 (below). (SST anomaly data: www.fnmoc.navy.mil/PUBLIC/, precipitation data: Proyecto Chira y Piura)

Meeresoberflächentemperatur-Anomalien während der Pre-Niño- und El Niño-Phase in den El Niño-Regionen 1 bis 4 (oben), während der Pre- bis Post-Niño-Jahre 1997 bis 2004 in den El Niño-Regionen 1 bis 3 mit Diagramm der monatlichen Niederschlagsmengen in Paita und Chulucanas (die Buchstaben p und c bezeichnen jeweils Niederschlagsmengen unter 10 mm/Monat) (Mitte) und während ausgeprägter Regenereignisse im März und April 2002 in den El Niño-Regionen 1 und 2 (unten). (Quelle der SST-Anomalienkarten: www.fnmoc.navy.mil/PUBLIC/, Niederschlagsdaten: Proyecto Chira y Piura)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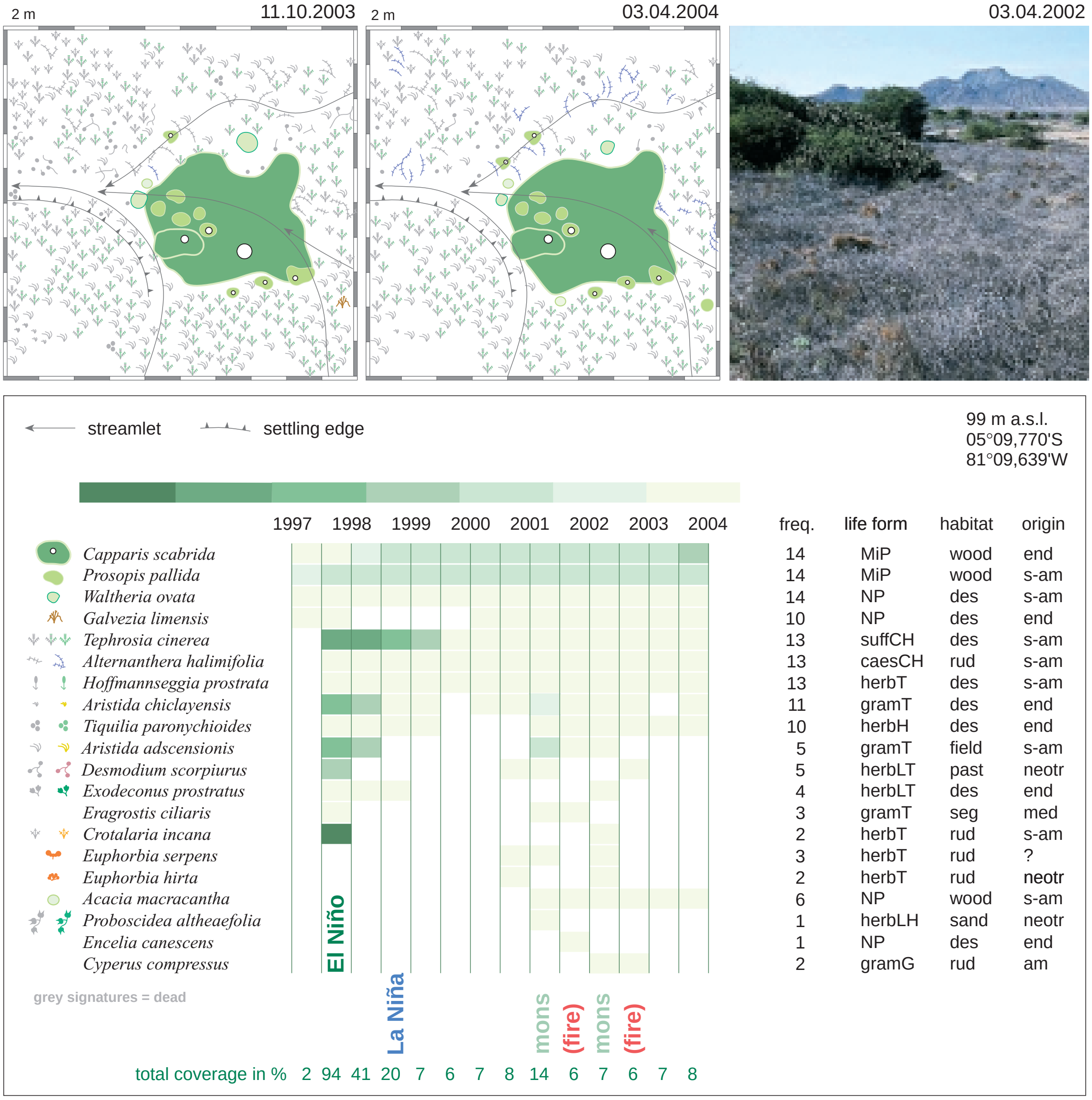


	freq.	life form	habitat	origin
Capparis scabrida	14	MiP	wood	end
Prosopis pallida	14	MiP	wood	s-am
Waltheria ovata	14	NP	des	s-am
Galvezia limensis	10	NP	des	end
Tephrosia cinerea	13	suffCH	des	s-am
Alternanthera halimifolia	13	caesCH	rud	s-am
Hoffmannseggia prostrata	13	herbT	des	s-am
Aristida chiclayensis	11	gramT	des	end
Tiquilia paronychioides	10	herbH	des	end
Aristida adscensionis	5	gramT	field	s-am
Desmodium scorpiurus	5	herbLT	past	neotr
Exodeconus prostratus	4	herbLT	des	end
Eragrostis ciliaris	3	gramT	seg	med
Crotalaria incana	2	herbT	rud	s-am
Euphorbia serpens	3	herbT	rud	?
Euphorbia hirta	2	herbT	rud	neotr
Acacia macracantha	6	NP	wood	s-am
Proboscidea altheaefolia	1	herbLH	sand	neotr
Encelia canescens	1	NP	des	end
Cyperus compressus	2	gramG	rud	am

Fig. 3: Plant development on a desert site near Paita: detailed sketches for one plot and table of mean coverage values of five plots. In contrast to the surrounding environments the sketched plot was not destroyed by fires. Nomenclature according to W³TROPICOS (SOLOMON 1999). Herbs and grasses react spontaneously to rainfalls and are shortlived whereas shrubs show a longterm increase in phytomass for six years after El Niño

Entwicklung der Pflanzendecke an einem Wüstenstandort bei Paita. Detaillierte Skizzen einer Fläche und Tabelle der mittleren Deckungsgrade von fünf Flächen. Die gezeichnete Fläche war im Gegensatz zur nahen Umgebung nicht von Bränden betroffen

common in desert environments receiving increased precipitation, the boost-effects of plant growth in our study area were not surprising. However, ecosystem changes resulting from the La Niña cold and the monsoon are not well understood.

3.2.1 *Response systems in the desert environment*

Before El Niño, plant cover in the area was restricted to 5 ± 3% of tree stands composed of an open *Prosopis pallida-Capparis scabrida* community (Fig. 3). Apart from these two prevailing tree-species only solitary shrubs of *Capparis avicennifolia* and *Waltheria ovata* were interspersed as further perennials. During the El Niño rainfall phase a rapid propagation of herbs and grasses built up a compact vegetation with a maximum coverage of 100 ± 20% within three months. This period was a crucial opportunity for seed dispersal, establishment, and replenishment. The open tree-stands now resembled a kind of a savanna, due to the dense herbal ground layer of a short-term *Aristida adscensionis-Tephrosia cynerea* community sprouting from a seed-bank dormant during non-ENSO years. This ephemeral herb and grass layer was quite patchy.

A 53% decrease in total plant cover occurred between March and October 1998 (Fig. 3). This indicates that the El Niño precipitation event affected fast-reacting herbs and grasses of short longevity, among which the annuals *Crotalaria incana* and *Desmodium scorpiurus* are the most important representatives. They comprised nearly 50% of total groundcover in March 1998; by October all had died. However, the grasses *Aristida chiclayense* and *A. adscensionis* were still vital, and *Tephrosia cynerea*, a chamaephyte that is lignified at its base, was at its maximum cover (25%) at this later date. *Tephrosia* dominated the plot through March 2000 but was slowly loosing vitality (Tab. in Fig. 3). It appeared like dead straw until 2004, but a few green leaflets indicated that it was still alive. *Tephrosia* as well as some associates, such as *Aristida adscensionis* and *Tiquilia paronychioides*, experienced revitalization after the monsoons in 2001 and 2002, accompanied by the newcomers *Acacia macracantha* and *Proboscidea altheaefolia*. In contrast to the herbs and grasses, the trees *Prosopis* and even more *Capparis* grew constantly and experienced a considerable regeneration: tree cover developed from 1.75% (1997) to 7.5% (2004); the regeneration is exemplified by 19 saplings of *Capparis scabrida* in one plot, concentrated in the shade of a *Prosopis* tree. Alien ruderals did not play an important role at this field site, because it is remote from cultivated land; only a few individuals of *Euphorbia hirta* and *E. serpens* entered temporarily after the monsoon rains.

Seven years after the Super-Niño several traces of the El Niño phenomenon are still visible (Fig. 3). Most of the annual and some of perennial herbs, vines, and grasses dominated by several taxa of Fabaceae and fewer of Poaceae had left behind a dense layer of straw. Apart from *Prosopis* and *Capparis* only *Waltheria, Galvezia*, and *Alternanthera* seem to have a chance of long-term survival, but *Tephrosia, Aristida, Tiquilia*, and *Acacia* are also still alive because of the precipitation in March-April 2001 and 2002.

Contrasting effects were tied to spotfires in mid-2001 and again in early 2002 (Tab. in Fig. 3). Embers saltating in strong trade winds from the south, left behind a structure of confined patches and stripes. The burned areas were cleaned from dry straw giving it back the desert appearance like it was before El Niño. Today, ongoing productivity and a long-term gain of biomass are restricted to woody species, most of them producing seed for future wet years.

Thus, fire as a macro disturbance is significant in the Paita area. However, the influence of micro-disturbances caused by burrowers is even higher. An outbreak of rodents became obvious at the study site, which was first noticed when subterranean holes collapsed underfoot in 1999 and 2000. They seemed to be concentrated on sites dominated by *Aristida* grasses, which causes the question if they are responsible for the patchy growth of herbs and grasses. Small rodent disturbances were first reported by PEARSON (1975) from the coastal Perú Desert after the 1972/73 El Niño. Recently, MESERVE et al. (1999) and JAKSIC (2001) showed a consistent connection between El Niño intrusions and rodent outbreaks in semiarid Chile: the rodent population boom lagged six months behind the plant-boost and then declined over the next two years.

Not surprisingly, there was an increased population of mice in our study site. The most prominent species, the gerbil leaf-eared mouse (*Phyllotis gerbillus*), is endemic to the Sechura Desert (STEPPAN 1996). This might result from the highly variable ENSO conditions restricted to the region. Other consumers of seeds are the Guayaquil squirrel (*Sciurus stramineus*) or the pygmy rice rat (*Oligoryzomys arenalis*); rabbits and previously the now extremely rare white-tailed deer (*Odocoileus virginianus*) are further herbivores. These primary consumers were followed one year later by increased predator populations. In the Sechura Desert, foxes (Sechuran zorro *Pseudalopex sechurae*) are the most widespread predators. Puma (*Puma concolor*) and pampas cat (*Oncifelis colocolo*) are nearly extinct and the Peruvian boa (*Boa constrictor ortoni*) does not play an important role any longer (information from the Museo de Historia Natural Lambayeque). Prominent members of the ecosystem are lizards among which desert tegu *(Dicrodon guttulatum)* and Peruvian crested swift (*Microlophus occipitalis*) are more widespread than curl tail lizard (*Tropidurus peruvianus*), false monitor (*Callopistes flavipunctatus*) and green iguana (*Iguana iguana*). The native burrowing owl (*Athene cunicularia nanodes*), as well as the migrating peregrine falcon (*Falco peregrinus*), American kestrel (*Falco sparverius peruvianus*), red back hawk (*Buteo polyosoma*), and cinereus harrier (*Circus cinereus*) may be secondary and even tertiary consumers. While this bottom-up model forms a logical trajectory, the top-down decline is a less simple non-linear complex. Instead, in the Paita area some of the plant species (Poaceae, most of the Fabaceae) serve as the principal triggers in the food chain but they break down abruptly. Others, such as *Capparis* and *Prosopis* continue to produce fruits for rodents, which apparently keep the predator/prey system alive for several years (even Sechuran foxes consume fruits of Zapote). Spotfires and/or burrowers – the question of which is the controlling factor for the patchy structure of the herbal layer following El Niño-rainfalls – remains unsolved.

3.2.2 Response systems in the dry woodland environment

In contrast to the coastal desert, human impact in the dry woodland environments of the interior is considerable. In many parts of the region livestock causes overgrazing effects and there are signs of desertification (reactivation of fossil dunes, complete eradication of trees, shrubs outcompeting herbs) in the drier parts. Degradation is also apparent in the Chulucanas area, where shrub encroachment and heavy trampling starts to diminish the carrying capacity. Here, environmental sensitivity is enhanced by highly permeable sand. Traces of a relatively dense streamlet system substantiate an episodic runoff. This area consists of a tree savanna with tree distances of approximately 15–30 m. *Cordia lutea* is now added to *Prosopis pallida* and *Capparis scabrida* while *Acacia macracantha* forms thickets. CHAMPIN LUY (1998, 2000) mentions very similar *Acacia aroma* var. *huarango*, syn. *A. aroma* and *A. huarango*, which also might exist in the area but is not distinguished from the by far dominant *A. macracantha* in this paper. Due to the short rainy season from January to April in non-ENSO years, a seasonal herb and grass layer occurs at the end of these periods (Fig. 4). This is a basis for moderate grazing by brahma cattle and goat. In non-ENSO years the thero- and hemicryptophytic stratum is extremely variable with coverages between 2 and 60%.

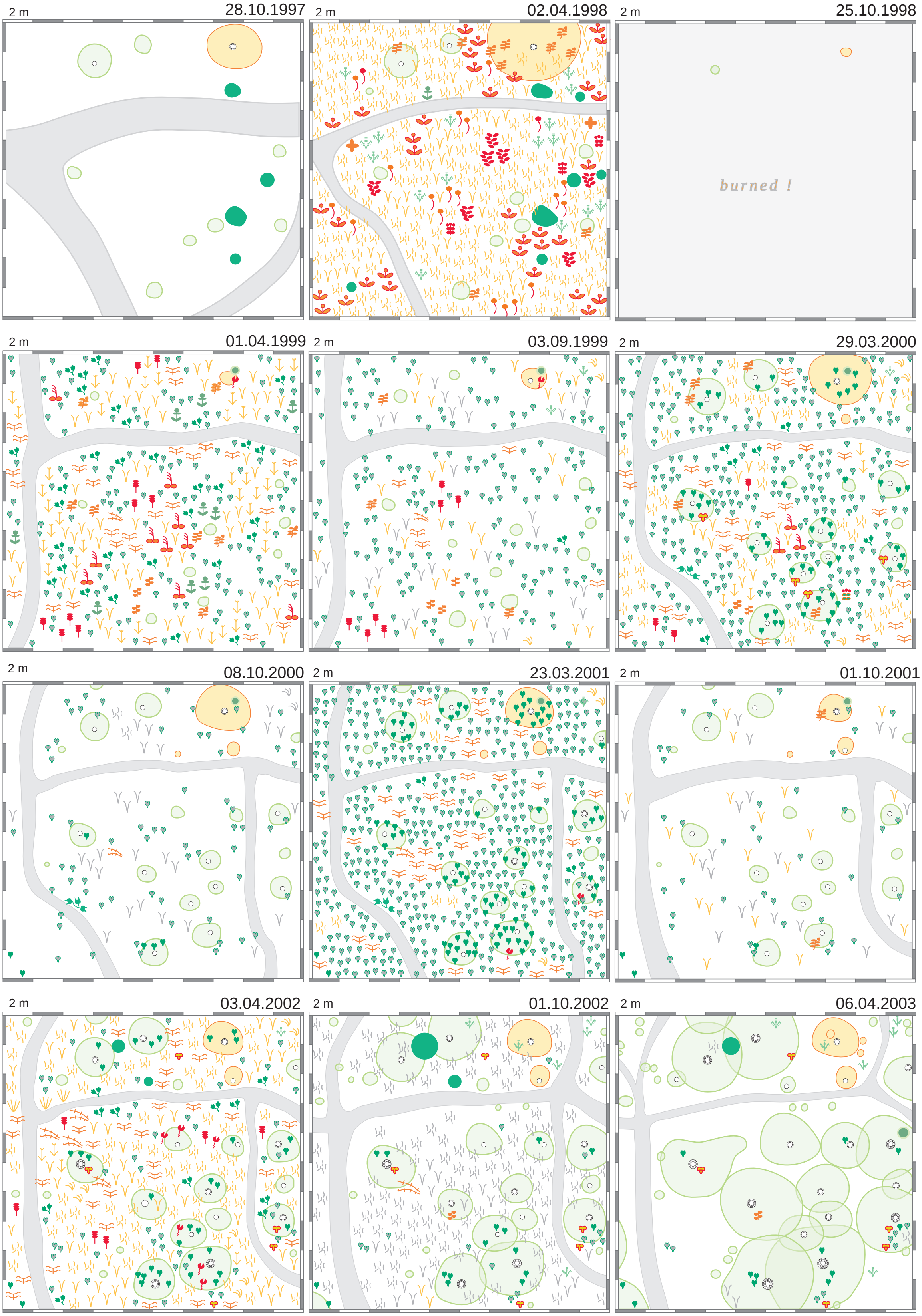
The final phase of El Niño was characterized by an extraordinary increase in productivity (Fig. 4). At the end of maximum plant growth the five plots were covered by the grasses *Anthephora hermaphrodita* and *Cenchrus pilosus* (44% and 27% respectively) associated with creeping herbs such as *Ipomoea tiliacea, Rhynchosia minima* and *Desmodium tortuosum* (totalling 13%). After the El Niño event the Chulucanas area was affected by a large fire (Fig. 4), which lasted three days from September 25th to 28th and flared up again on September 30th. It destroyed 12,732 ha and was probably caused by honey collectors who set small fires to produce smoke to repel bees. Such incidents are rather frequent during a dry season after an El Niño event. Fires were reported by local farmers for the 1992 post-Niño phase as well as in July and August of 1998 in the same area. While these prior incidents were controlled quickly, the last one could not be extinguished due to its relative inaccessibility and its rapid expansion. Fires are restricted to post-Niño phases, when straw accumulates. In subsequent years we observed burned areas in several locations along the road between Paita, Piura, Chulucanas and Olmos. According to BRAVO FERRO (2001), 106,000 ha were incinerated. Reports from the Galapagos described similar effects after the 1982/83 Super-Niño (GARA et al. 1987).

Floristic changes due to the post-Niño fire were greater than those from El Niño precipitation. Usually, strawfires in savanna ecosystems are surface fires with little damage to trees, because the straw accumulation is low density (0.5 kg/m^2 of the average 20–40 cm high stratum in the Chulucanas case according to CHAMPIN LUY 1998). At the Chulucanas site, lightly burned trees with dry but still visible foliage indicated that the flames rushed through, driven by the diurnal southern trade winds. In some few areas, however, even the uppermost canopy foliage was completely burned. For these smaller patches higher fire intensities during nocturnal calms is presumed.

In general, a complete destruction of the herbal layer occurs but only a few individuals of the woody species are killed. Within the greater area, ~95% of *Capparis scabrida* re-sprouted leaves immediately after the fire. *Cordia lutea* exemplified a similar survival rate by re-sprouting from roots the next rainy season. *Prosopis pallida* showed a retarded development of leaflets. Its mortality was higher than that of *Cordia*, with around 10% and locally much more. Shrubs of *Acacia macracantha* have been intensively damaged. Accelerated post-fire fructification and germination was obvious for *Capparis scabrida*, which in many cases proliferated in clumps below re-sprouted trees or shrubs

Fig. 4: Plant development on a dry forest site near Chulucanas analogous to figure 3. Vegetation development is differentiated more than in Paita because of fire disturbance and greater precipitation. In the final phase saplings of acacia show high growth rates documenting the regenerative power of El Niño for the dry forest ecosystem. Photo: *Exodeconus prostratus* sprouting after the 1998 fires

Entwicklung der Pflanzendecke an einem Trockenwaldstandort bei Chulucanas, analog zu Figur 3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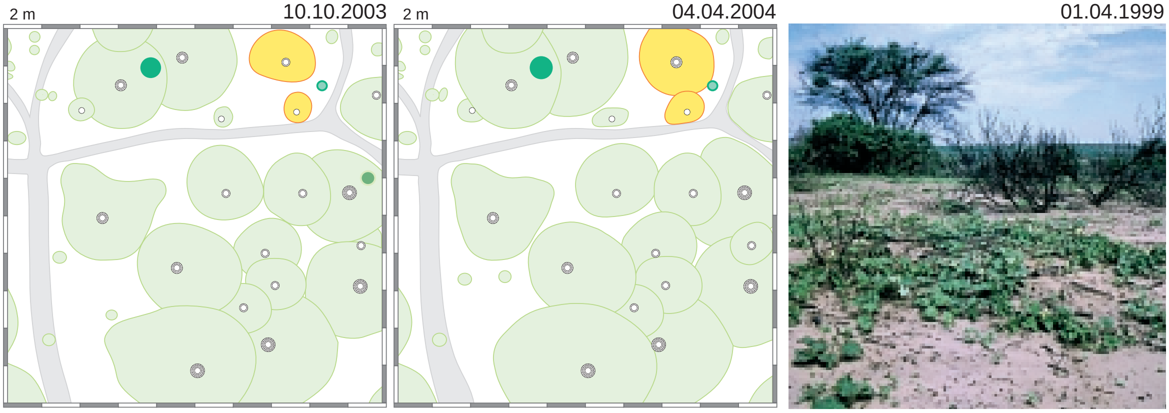
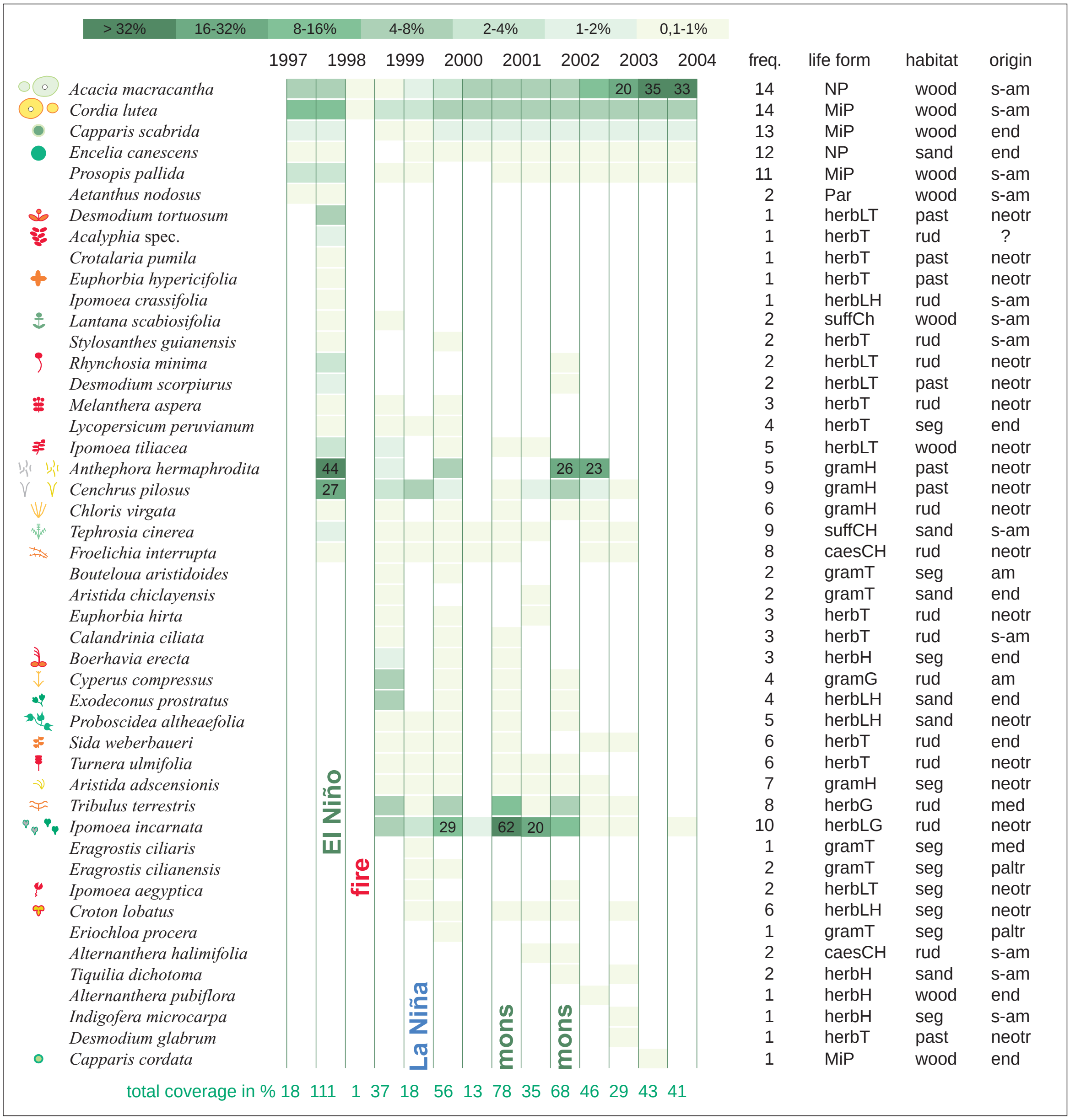




	freq.	life form	habitat	origin
Acacia macracantha	14	NP	wood	s-am
Cordia lutea	14	MiP	wood	s-am
Capparis scabrida	13	MiP	wood	end
Encelia canescens	12	NP	sand	end
Prosopis pallida	11	MiP	wood	s-am
Aetanthus nodosus	2	Par	wood	s-am
Desmodium tortuosum	1	herbLT	past	neotr
Acalypha spec.	1	herbT	rud	?
Crotalaria pumila	1	herbT	past	neotr
Euphorbia hypericifolia	1	herbT	past	neotr
Ipomoea crassifolia	1	herbLH	rud	s-am
Lantana scabiosifolia	2	suffCh	wood	s-am
Stylosanthes guianensis	2	herbT	rud	s-am
Rhynchosia minima	2	herbLT	rud	neotr
Desmodium scorpiurus	2	herbLT	past	neotr
Melanthera aspera	3	herbT	rud	neotr
Lycopersicum peruvianum	4	herbT	seg	end
Ipomoea tiliacea	5	herbLT	wood	neotr
Anthephora hermaphrodita	5	gramH	past	neotr
Cenchrus pilosus	9	gramH	past	neotr
Chloris virgata	6	gramH	rud	neotr
Tephrosia cinerea	9	suffCH	sand	s-am
Froelichia interrupta	8	caesCH	rud	neotr
Bouteloua aristidoides	2	gramT	seg	am
Aristida chiclayensis	2	gramT	sand	end
Euphorbia hirta	3	herbT	rud	neotr
Calandrinia ciliata	3	herbT	rud	s-am
Boerhavia erecta	3	herbH	seg	end
Cyperus compressus	4	gramG	rud	am
Exodeconus prostratus	4	herbLH	sand	end
Proboscidea altheaefolia	5	herbLH	sand	neotr
Sida weberbaueri	6	herbT	rud	end
Turnera ulmifolia	6	herbT	rud	neotr
Aristida adscensionis	7	gramH	seg	neotr
Tribulus terrestris	8	herbG	rud	med
Ipomoea incarnata	10	herbLG	rud	neotr
Eragrostis ciliaris	1	gramT	seg	med
Eragrostis cilianensis	2	gramT	seg	paltr
Ipomoea aegyptica	2	herbLT	seg	neotr
Croton lobatus	6	herbLH	seg	neotr
Eriochloa procera	1	gramT	seg	paltr
Alternanthera halimifolia	2	caesCH	rud	s-am
Tiquilia dichotoma	2	herbH	sand	s-am
Alternanthera pubiflora	1	herbH	wood	end
Indigofera microcarpa	1	herbH	seg	s-am
Desmodium glabrum	1	herbT	past	neotr
Capparis cordata	1	MiP	wood	end

total coverage in % 18 111 1 37 18 56 13 78 35 68 46 29 43 41 through the provision of shade. Also the survival of *Capparis* sprouts was much higher than of *Prosopis*, which is preferred by cattle (Champin Luy 2000).

While the existing woody plants recovered without major taxonomic change during the rainy season after the fire event, species composition of the herbal cover altered considerably. *Tribulus terrestris* and *Ipomoea incarnata*, although absent after ENSO precipitation, invaded and now prevailed (Tab. in Fig. 4). *Tribulus* is a Mediterranean weed while the origin of *Ipomoea* is not clear but might be from Brazil, where it is recorded as a roadside and post-fire weed (Virtual Herbarium NYBG 2003; in an earlier paper by Block and Richter (2000) *I. incarnata* was misinterpreted and cited as *Convolvulus arvensis*). Among further pioneers, pantropical *Cyperus compressus* and endemic *Exodeconus prostratus* were frequent species after the fire, and *Lantana scabiosifolia* was abundant (Fig. 4). In 1999, La Niña was complicating the situation: rainstorms in February and April slightly enhanced total precipitation to 416 mm through May, thus contributing to the vitality of *Tribulus* and *Ipomoea*. Furthermore, besides the still booming *Ipomoea*, the native therophytic ruderals *Sida weberbaueri* and *Turnera ulmifolia* profited from the surplus moisture and probably also from the cooling effect of La Niña. *Cenchrus pilosus* grew once again but not as much as during El Niño. The 2000 rainy season caused a weak comeback of *Anthephora hermaphrodita*. Many of the post-fire "newcomers" survived or returned after the following rainy seasons.

Both *Tribulus terrestris* as well as *Ipomoea incarnata* reacted to the monsoon rainfalls, the latter with coverage values of 62% in October 2001. The increasing abundance of some species after the fire may be explained by their ability of vegetative reproduction: this is true for *Cyperus compressus* as well as the low-creeping *Tribulus terrestris* and climbing *Ipomoea incarnata*. These species can be considered fireweeds, while all remaining ruderals propagate only by seed dispersal. Vegetative sprouting was observed throughout the region on sandy soils lacking in carbon and nitrogen, where the establishment of seedlings is generally slow (Valk 1992). This was not the case in the pre-fire situation since the post-rainfall plantcover was completely built up by sprouts germinating from the seed bank. After burning, a more patchy community structure was created by the accumulation of ashes, straw, and raw humus in small depressions or gullies where it concentrated in thick layers. However, most of the surface was denuded of organic nutrients which probably promoted those ruderals of the so called "guerrilla-type", building up herds expanding by offshoots (Symonides 1985).

During the first three years after the fire *Acacia macracantha*, a widespread invader of disturbed or cleared land in the semiarid Neotropics, did not make major progress. After a slight oscillation of increasing coverage by October in the years 1999 through 2002, the years 2003, 2004 were marked by an enormous gain in growth rates (Fig. 4). While the last sketch of the mapped plot in figure 4 (April 2004) indicates a coverage value of around 60%, the average for all plots is still 33%. This fact is most surprising as 2003 and 2004 were extremely dry years. The rainfall surplus of 2001 and 2002 did not result in significant increase of shrub girth but instead contributed to profound root development indispensable for drought tolerance. During the last dry period most of the herbs and grasses died: this coincided with enhanced grazing pressure, especially by goats. Thus, the moisture in 2001 and 2002 followed by dessication in 2003 and 2004 combined with the fact that livestock ignore *Acacia*, allow this species to flourish under drought conditions. Because of this, *Acacia* is now the dominant species. This might indicate desertification processes as described by Schlesinger et al. (1990) or Holmgren and Scheffer (2001). Consequently these alternating processes are a sign of a continuous spiral typical in dry woodlands in northwestern Perú: the positive trends of a potential natural recovery are accompanied by negative effects from enlarged livestock flocks and resultant overgrazing, hence plant development once again experiences a setback. In this case, increased vegetation coverage does not necessarily coincide with increased fodder supply.

Since fire events are not restricted to the savanna-type ecosystem but occur in the coastal deserts as well, ecosystems in the region are thus sensitive to multiple disturbance regimes. Ruderals build extensive seed banks, therefore in the case of El Niño, they are most efficient as we see with the example of *Ipomoea* and *Tribulus*.

3.3 Succession and retrogression: a synthesis

In the introduction we hypothesize that floristic elements of another vegetation-zone should be capable of entering and establishing themselves in the desert environment for limited periods and that the fifty-fold increase in precipitation – as was the case in Paita – should cause greater variations in plant cover than the twelve-fold increase that occurred in Chulucanas. We conclude now, that this is true for the initial phase after El Niño. In the following phase successive and retrogressive trends are more complex. This is displayed by the coverage values shown by the diagrams of figure 5.

In the case of the Chulucanas site the uneven heights of the bars (Fig. 5, right) reflect oscillating trends in plant growth. In contrast, at the Paita site, the development is restricted mainly to the outstanding peak due to the ENSO rainfall-boom (Fig. 5 left). Here, water deficits prevail during the entire post-Niño phase with the short monsoon period in 2001 causing only a slight temporary increase in plant cover. Even less effective is the stronger monsoon or Niño-like event in 2002, since the spotfires swept off the effect of the higher water input during March and April (Fig. 2). Thus, different development trends in the desert and in the dry woodland are evident.

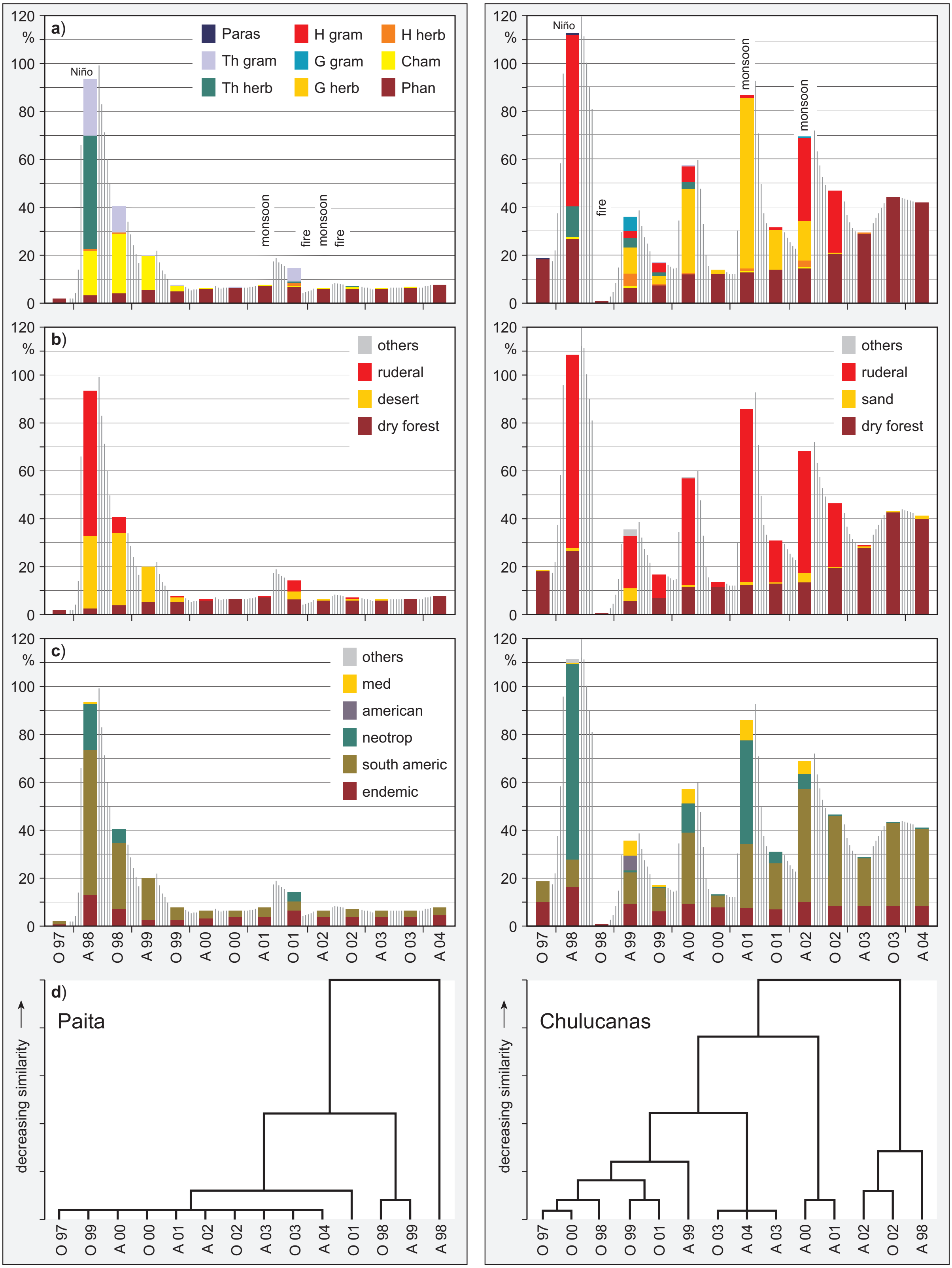
At the desert site of Paita, the short-term boost causes a considerable deviation from the poor coverage during the dry conditions of non-ENSO periods (Fig. 5, left). Therophytic herbs such as *Crotalaria, Desmodium*, and *Exodeconus* were the first prominent participants of the micro-succession which began within one month after the first rains (Fig. 5a, left). The therophytic grasses of *Aristida* and hemicryptophytes such as *Alternanthera, Tephrosia*, and *Tiquilia* followed in the next few weeks in February 1998, and showed a longer survival rate. All of these temporary taxa are of neotropical origin, most of them from South America including the widespread algarrobo-tree *Prosopis pallida*. Few grasses and herbs are endemic, which is also true for the perennial species of *Capparis, Galvezia* and *Walteria* (Fig. 5b, left). While the quasi-permanent non-ENSO community consists mainly of woody representatives of the dry forest, the associated herbs and grasses of the short-term ENSO-community originate from desert habitats or are considered native ruderals (Fig. 5c, left). Only during the outstanding peak coverage within the Niño boom, taxonomic and structural compositions are marked by strong divergence from the usual. The dendrogram in figure 5d (left) reveals a fast assimilation of the post-Niño community back towards the pre-Niño situation as a crucial feature for plant successions in the Paita area. The parallel investigations on sandy and rocky sites corroborate this fundamental result for desert environments, where no effective long-term community change can be expected after Super-Niños.

In general, there is a rather stable floristic composition of woody species. Only a few trees grow temporarily, such as the non-indigenous *Parkinsonia aculeata*. Clumped herds of this species can be observed in the ditches of paved roads. The permanent vegetation changes more in structure than in composition as Super-Niños trigger tree growth decisively. Within the Paita study site this stability is notable until the second burning in mid-2002, which caused a temporary setback of phanerophytic coverage. Nevertheless, the enforced primary production of woody species as a reaction to the heavy rainfalls is likely to be an outcome of renewed ground- and porewater reservoirs and thus of a higher moisture availability.

The dendrogram of Chulucanas displays a much more vivid vegetation change than that of Paita (Fig. 5d). Four groups can be distinguished: the first one (left) is characterized by low coverage values. It includes most samples from the dry seasons (October 1997–2001) and April 1999, when plant cover was still low due to fire. The second group is joined with the first one and comprises the last phase of development, i.e. the remaining dry community including the final enlargement of *Acacia*-shrubs (from October 2003 to now). The third group is less similar; the unit is marked by the boost phase of *Ipomoea incarnata* and *Tribulus terrestris* (April 2000 and 2001) which we interpret as a retarded reaction to the surface fire. The last group shows an outstanding dissimilarity to the other groups. It consists of post-rainfall associated plants and indicates that the effects of the second monsoon in 2002 are comparable to those of the Niño event in April 1998.

The evaluation of origin (Fig. 5c) and habitat characteristics (Fig. 5b) of all Chulucanas species results in the following relations: some of the species are not native but from Central America or even from the Old World. Those aliens are mostly weeds escaping from fields or roadsides with remarkable invasive ability. For many of the associated ruderals it is not yet possible to reconstruct their exact origin. Nevertheless, many of them, such as *Ipomoea incarnata* or the grasses *Anthephora* and *Cenchrus*, are assumed to be "neotropical". Most of the South American herbs must be considered as widespread invaders too, but not so the endemic species since they originate from coastal and inland dunes. In contrast to the multiple provenances of the herbs and grasses the perennial woody plants are exclusively native. Hence, the quasi-permanent non-ENSO woody community consists of indigenous species, whereas the episodically promoted short-term herb and grass layers of ENSO, monsoon, and post-fire events in the inland are dominated by many non-indigenous ruderals and a lower number of native sand species.

After the Niño-rainfalls as well as after the second monsoon precipitation, hemicryptophytic grasses and herbaceous climbers prevailed (Fig. 5a, right); this is in response to the increased moisture input. In two cases (April 2000 and 2001) geophytes sprouting from rhizomes or tubers were most apparent members of the post-fire development (Fig. 5a, right). Finally, the most recent increase in coverage is linked to the shrub expansion of *Acacia*. Its propagation was first hampered by the root competition among herbs, grasses, and shrub shoots within the upper rhizophere. After an initial activation of a plentiful seed bank, relatively few individuals of *Acacia* survived up to a point of abruptly augmenting growth rates. This point coincides with the


a)
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Niño
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Cham
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others
ruderal
desert
dry forest
sand
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american
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decreasing similarity
Paita
Chulucanas
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state when roots reached deep soil moisture. We assume that after this "break-through" a high survival rate is the case, even through a future long-term desiccation.

In Paita, variations in plant coverage between more and less rainy seasons are hardly notable, while the Chulucanas site displays a significant dependence on the more variable rainfalls. Furthermore, in Paita, therophytes and slightly lignified chamaephytes play a decisive role restricted to the first part of succession, whereas the life-form spectra of Chulucanas are characterized by longer lived hemicryptophytes, geophytes and micro-phanerophytes. Native elements rule the floristic structure of the plots at Paita, while more widespread and invasive ruderals govern the ecosystems in Chulucanas. This results from the differing human impact intensity: grazing as well as irrigated field cultivation in the hinterland promotes the input and propagation of wind- and animal-dispersed (i.e. exozoochorous) weeds, some of them neglected by cattle; at the coast grazing is minimal and there are no fields. The response to Super-Niño 1998 and the two monsoon events lead to an increasing distribution of shrubs and trees. We see this as a savannification process. However, at the same time overgrazing may lead to a degradation of the floristic composition.

4 *Climate change and vegetation development: dangers and opportunities*

Based on a 15,000-year continuous record of lake sediments in Ecuador, RODBELL et al. (1999) demonstrated that the modern El Niño climate pattern in the northern Central Andes did not become established until about 5,000 years ago. Since then, after the sea level had stabilized following a period of rapid rise (ENFIELD 1992), various ENSO proxy indices (records by marine sediments, ice-cores, ocean settings, tree-rings etc.) carry evidence of the El Niño phenomenon. Sand deposits in the catchments of the Rios Piura (Fig. 1) and Chira seem to result from strong Niño-phases between 3,900 and 3,600 BP as well as between 2,800 and 2,500 BP (MARTIN et al. 1993). Furthermore, fluvial accumulations of the Rio Casma indicate a return rate of around 1,000 years for "Mega-Niño events" which by far exceeded the intensity of recent Super-Niños (WELLS 1990). Thus irregular Niño-frequencies and -intensities seem to be a normal natural phenomenon.

Results from high-resolution ocean-atmosphere models presented by LATIF et al. (1997) and TIMMERMANN et al. (1999) show that the recent Niño-phase must not be judged as normal, but rather as a superposed low-frequency trend within a climate change that will be accelerated over the coming decades. By coupling the model with a rise of man-made CO_2-emissions TIMMERMANN et al. (1999) supposes an increase of SST of >3K for the eastern tropical pacific region up to the year 2100 (Fig. 6). In this context a greater probability of a higher intensity and frequency of Niño-like weather events, including the monsoon effects, becomes realistic.

The precipitation record in Piura (Fig. 6) starts in 1932; it is the longest time line available for northwestern Perú. A phase of relatively high precipitation activity has been recorded between 1930 and 1945 followed by a drier phase until 1973. With the Super-Niño of 1982/83 a phase of increased Niño frequency and greater intensity seems to begin, including a smaller event in 1986/87 as well as the double-Niño 1991/93, and culminating in the recent 1997/98 phenomenon (BENDIX et al. 2000). The same trend is found in the much longer chronology of El Niño indices presented by QUINN et al. (1987).

Of course, it is speculative to link a single ENSO event with climate change and hence, with ecosystem change. Nevertheless, the attempt to illuminate possible post-Niño vegetation scenarios is important, as the actual knowledge provides appropriate ideas. A more frequent disturbance regime obviously shortens the cycles of a system and offers more possibilities for pioneer species to occur, ruderals included. Consequently, a future rapid change in weather phenomena supporting boost effects must accelerate the input of invasive ruderals and might lead to an explosive enrichment of its most dominant species. As presented here, there is evidence in northwestern Perú that in the case of El Niño 1997/98 short-lived species are most efficient at taking advantage of the phenomena.

Fig. 5: Development of life forms (a), habitat preferences (b) and origin of species (c) as well as floristic similarity in time (d) between 1997 and 2004 at the Paita and Chulucanas sites

Entwicklung der Lebensformen (a), Habitatzugehörigkeit (b) und Herkunft der Arten (c) sowie floristische Ähnlichkeit in der Zeit (d) von 1997 bis 2004 auf den Standorten bei Paita und Chulucanas

An advanced interpretation might be achieved by revealing to what extent the "vegetation of the moment" may change under more frequent Niño- and Niño-like (monsoon) events. In the case of no human impact on vegetation the most recent relevés at Paita give hints for future development. For example, *Alternanthera halimifolia* and *Tephrosia cynerea* had negligible abundance in the study plots up to the last Super-Niño. However, most recent observations display a tendency of possible survival of these species if the frequency of El Niño-cases or unforeseen moist-warm incidences will increase. Although the distribution patterns of those exemplary species will fluctuate, they might persist as new core species. Shrubs such as *Galvezia limensis* and *Waltheria ovata* are indicating a progression as well; they are prospering in flat depressions and gullies. Even the immigration of shrubby *Acacia macracantha* and *Encelia canescens* is believable, as roadside observations between Piura and Paita indicate their progression towards the coastal desert. Further propagation of the most abundant trees *Prosopis pallida* and *Capparis scabrida* is obvious: *Prosopis* by spreading, *Capparis* by both spreading and increased germination rate.

The input of anemochorous exotic ruderals from long distances is of minor importance but exists, as verified by scattered temporary bunches of *Chloris virgata*. However, in natural vegetation, droughts, fires, storms and floods will not cause floral changes if ruderal seed pools are not available. Our observations from the untouched Loma vegetation in northern Chile indicate that the last El Niño did not favour any ruderals (cf. MUÑOZ-SCHICK et al. 2001). Thus, future ruderalisation released by destructive or favourable weather conditions is restricted to areas recently populated and influenced by man.

In terrains with grazing and an increase of farming typical for the inland regions, diverse dynamic characteristics and strategies of invading ruderals such as cohort senescence, toxic effects and competitive or regenerative qualities must be considered. Recent post-fire expansion of *Acacia macracantha* and also of *Cordia lutea* leads to a further propagation of the shrubby members,

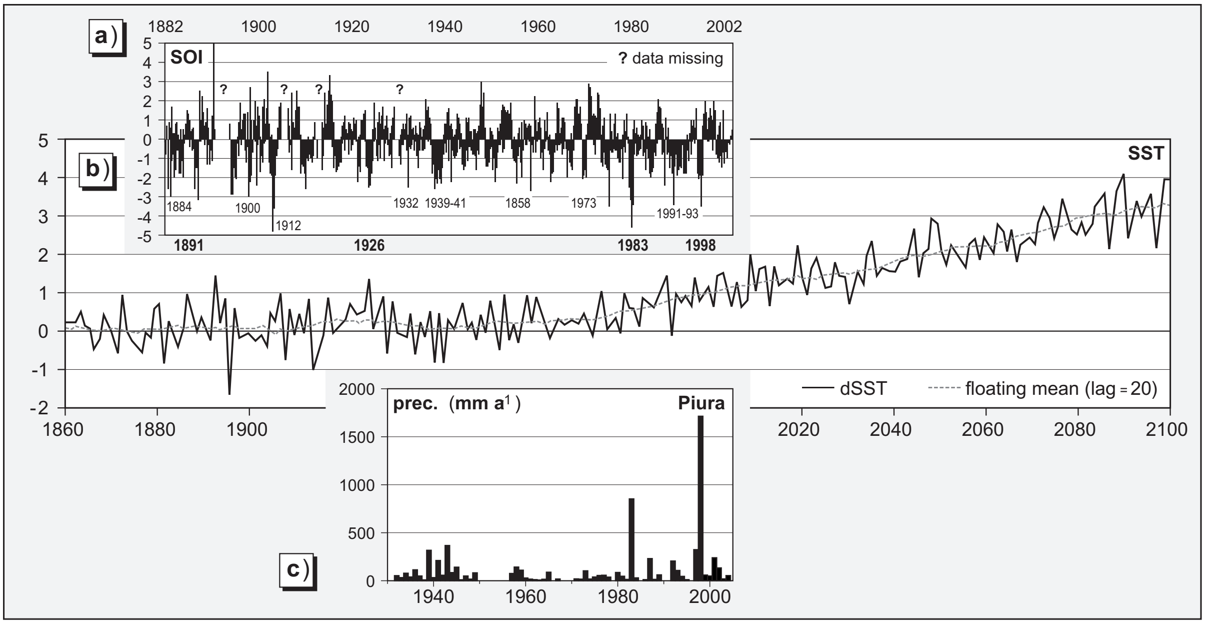

Fig. 6: Indicator values for past and future El Niño activity: (a) Southern oscillation index (SOI) between 1882 and the present (source: http://sevilleta.unm.edu/data/contents/SEV016/), (b) development of sea surface temperatures (SST) between 1860 and the present and scenario of a future increase based on coupled ocean-atmosphere models (source: BENDIX et al. 2000) and (c) annual rainfall amounts at Piura from 1932 until now (Data: Proyecto Chira y Piura)

Indikatoren für vergangene und zukünftige El Niño-Aktivität: (a) SOI-Werte zwischen 1882 und heute (Quelle: http://sevilleta.unm.edu/data/contents/SEV016/), (b) Meeresoberflächentemperaturen (SST) von 1860 bis heute und Szenario der zukünftigen Entwicklung nach gekoppelten Ozean-Atmosphärenmodellen (Quelle: BENDIX et al. 2000) und (c) Jahresniederschlag in Piura von 1932 bis heute (Daten: Proyecto Chira y Piura) which might hamper the two dominant tree species by root competition. A progressive invasion of additional annuals may lead to a provisional release of new satellite species, while non-native perennial herbs may increase the total vegetation cover. Cohort mortality of *Ipomoea incarnata* might be a consequence of even-aged populations smoothing the way for other invaders. Later on, whether there will be a collapse or a renewal of dominant taxa, a decline of native herbs must occur as an inevitable temporary fact: at least in transitory phases, plant selection by grazing as well as by specific inhibitory substances, might produce permanent fluctuations in species numbers.

Thus, concerning its effects on vegetation, climate change can not be regarded as being dissociated from global change. According to BEERLING (1995) human activity in combination with an increased frequency of extreme events allows species invasions and homogenizes species composition on a zonal scale. "Phytoglobalization", i.e. an accelerated mobility of invaders by human impact, is triggered by and connected with the increasing economic trade and mobility of people (RICHTER 2001). Extreme weather situations due to a change in circulation patterns may cause new types of disturbances or new magnitudes of boost effects, thus giving space for plant invasions. Whether equivalent processes in northwestern Perú must be considered dangerous depends on one's personal opinion – at least invaders do not seem to threaten the desert ecosystems in a substantial way.

However, a real problem is the decline of plant productivity and land degradation resulting from overgrazing because El Niño rains allow peasants to expand extensive goat breeding. In principal, the peasants are right since many land-use experts and ecologists are beginning to emphasize the positive effects of El Niño, for example now discussing a "window of opportunity for the restoration of degraded arid ecosystems" (HOLMGREN a. SCHEFFER 2001). Thus, forecasting ENSO episodes is employed for semiarid rangeland and production systems to identify the risk of overgrazing and fire during dry years and to stimulate pasture and woodland regeneration during and after rainy years (HOLMGREN et al. 2001).

Positive effects on natural tree germination after El Niño 1982/83 induced the "Proyecto Algarrobo" to carry out a program of reforestation with *Prosopis pallida* which started in 1992 by sowing seeds from small airplanes covering 1,200 ha of rural community land south of Piura (VILELA PINGO 2002). In 1996 and 1997, i.e. just before the 1997/98 event, the same project organized an initiative with participation of the rural population to disperse *Prosopis* seeds on 10,090 ha. The Algarrobo-tree is not only respected as a powerful symbol, resisting dry environs but also provides products such as hard timber and charcoal, fodder for cattle, as well as nectar for apiculture and healthy essences. Furthermore, it creates valuable shade for the recovery of undergrowth. However, over-exploitation of *Prosopis* occurs during dry phases of non-ENSO years.

In northwestern Perú, the problem of pressure on forest resources is neither tied to a lack of knowledge on the part of agro-engineers or scientists nor to a lack of governmental or non-governmental projects on sustainable planning. In contrast, the department of Piura is supervised by a surprisingly high number of state offices with an environmental and agro-ecological orientation, which produce useful papers providing technical information. However, the central interest is that the rural population develops primary responsibility for future forests, and the need for policies that guarantee their appropriate use and conservation (VALÁSQUEZ MILLA 2003). In this case, the bridge between the department of Piura and the local people needs to be strengthened, as the number of administratives is greater than that of consultants.

Enhanced productivity from El Niño precipitation contrasts with the widespread effects of desertification. Although being only a temporal event, a recovery during the post-Niño phase may be based on the resilience of the still existing woodlands. The long-term effects of a brief regeneration cycle offer a worthwhile situation to use rainfall in the most efficient way. Consequently, the three to four years following a strong El Niño event are a period of highest importance and enhanced necessity to support and control the regeneration processes, which are driven by the energy flows within the terrestrial ecosystems in northwestern Perú.

Acknowledgements

We thank Donald Friend, Senior Fulbright Scholar, Erlangen and Prof. of Geography, Minnesota State University, USA, for intensive discussion and help with the English language. José Ayastae and Ana Juarez, students of the Dept. de Biología Univ. Lambayeque, as well as Glenda Mendieta, student of the Dept. de Biología Univ. Piura, for fruitful discussions and their assistance with plant and animal identification; Eric Rodriguez Rodriguez and Elmer Alvitez Izquierdo for logistic support and for helpful scientific introduction during an excellently organized national botanical congress in Trujillo 2004; Sr. Felix Zapata, Proyecto Chira y Piura, for the supply of reliable climate data.

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