**July 2011** **Working Paper FNU-196**

# Assessing the Predictability of Future Livelihood Strategies of Pastoralists in Semi-Arid Morocco under Climate Change

Korbinian P. Freier [a,e1], Rainer Bruggemann [b], Jürgen Scheffran [c], Manfred Finckh [d], Uwe A. Schneider [e]

[a] International Max Planck Research School on Earth System Modeling (IMPRS-ESM), Bundesstr. 53, D-20146 Hamburg, Germany
[b] Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Müggelseedamm 310, D-12587 Berlin Germany
[c] Research Group Climate Change and Security, Institute for Geography and KlimaCampus, Hamburg University, ZMAW, Bundesstrasse 53, D-20146 Hamburg, Germany
[d] Biocentre Klein Flottbek and Botanical Garden, University of Hamburg, Ohnhorststr. 18, D-22609 Hamburg, Germany
[e] Research Unit Sustainability and Global Change, Center for Marine and Atmospheric Research, Hamburg University, Bundesstr. 55, D-20146 Hamburg, Germany

## Abstract

This study assesses the predictability of future livelihood strategies of transhumant pastoralists in semi-arid Morocco. A decrease in precipitation due to climate change will likely threaten their traditional livelihood strategy. We examine whether the pastoralists explicitly prefer certain alternative strategies or if their reactions will be contingent. Our analysis uses standardised interviews focussing on two aspects: Firstly, which resources are necessary for the pastoralists to be able to choose a livelihood strategy? Secondly, to what degree are expectations of well-being satisfied by alternative strategies? To assign levels of predictability to all investigated strategies, we analyze the interviews using simple methods of partial order theory. We find that under perceived precipitation scarcity, 38% of pastoralists would explicitly opt for sedentarity and localized

[1] Corresponding author. Tel.: +49 40 428387243; Fax: +49 40 428387009.
E-mail address: korbinian.freier@zmaw.de (K.P. Freier)

pastoralism as alternative strategy. Unclear preferences are given for 25% of the cases. Considering a policy scenario of enhanced access to education and capital, our analysis indicates commercial pastoralism as dominant alternative. However, such a scenario would increase the share of unclear preferences to 43%, which increases the likelihood of a contingent development. The method we propose can be considered as a mathematical basis for the concept of historical contingency.

## Introduction

In our study we assess the predictability of future livelihood strategies of transhumant pastoralists in semi-arid Morocco. The region of interest is likely to experience considerable alterations in precipitation during the 21$^{st}$ century (Born *et al.*, 2008), leading to modifications of livelihood strategies and agricultural techniques. The extent to which livelihood strategies will be modified is unclear, since socio-ecological systems are traditionally considered as very difficult to predict. Reasons for poor predictability are a high complexity of internal structures and involvement of partly unpredictable human agency (e.g. (Berkes, 1999; Crane, 2010)).

Given these constraints on predictability, social sciences mostly investigate socio-ecological systems from a historical perspective. Random events, which strongly impact the subsequent development of these systems, are considered as so-called historical contingencies which lead to path-dependence (Mahoney, 2000; Bennett & Elman, 2006; Beyer, 2010; Goldstone, 1998). Historical contingencies are seen as an irreducible gap in the causal narrative (Bennett & Elman, 2006) and therefore principally prevent valid predictions about socio-ecological systems.

In contrast to social sciences, physical sciences are very much oriented towards giving predictions. If natural processes are sufficiently understood, limits to predictions within physical models arise mainly from deficiencies in measurement accuracy. For example, chaotic systems can be regarded to a certain extent as unpredictable, since infinitesimal deviations in initial conditions can completely alter future states. In such systems, accuracy of predictions decreases towards a certain time-horizon. After that time-horizon an exact calculation of future states is unfeasible (Lorenz, 1963). Lack of predictability

also relates to concepts of inherent randomness (Regan *et al.*, 2002) or deep uncertainty (Walker *et al.*, 2010), where predictability is restricted because the system is irreducible to a deterministic one. Despite these principal limits, physical assessments of socio-ecological systems aim at giving valid predictions in order to enable rational decision making by actors within the system or by agents which control boundary conditions. However, it is disputable whether or to which degree socio-ecological systems can be described by physical concepts (Hauhs & Lange, 2008; Rosen, 1991).

Considering these different perspectives of social and physical sciences, an integrated assessment of socio-ecological systems holds considerable challenges for the scientific community. For instance, decision making within such systems which has relied too much on physically motivated predictions often has failed due to excessive confidence in such predictions (Scott, 1998). On the other hand, using a historical perspective for planning is not able to include new social and environmental situations such as technological advances and climate change. Planning and rational decision making is therefore mainly constrained to adaptive methods which are designed to be able to include unforeseen elements during the run of their implementation (Walker *et al.*, 2010). However, adaptation of societies to altered environmental conditions may require early investments. For the planning and realization of these investments, decision makers benefit from knowing the degree to which a specific socio-ecological system can be considered as predictable and how the predictability changes in response to technological and environmental developments.

Here, we present and apply a mathematically formalized way of investigating the predictability of future livelihood options of a pastoral society in southern Morocco. We assume that contingency mainly arises from the pastoralists' decisions. For instance, facing decreasing precipitation, pastoralists will behave more predictable if they have clear preferences about alternative agricultural techniques and alternative livelihood strategies. To assess the level of predictability of the pastoralists' decisions, we use standardized interviews based on a multi-criteria ranking to analyze the background of relevant preferences of the pastoralists. Predictable parts of expected behaviour will than be separated from unpredictable ones by using simple methods of partial order theory.

## Methods

## *Study region and research questions*

Fieldwork for our study was performed in summer 2009 in the upper Drâa catchment in the High Atlas Mountains of southern Morocco (Ouarzazate Province). Being part of the Moroccan "migration belt", 65% of households in the Drâa valley depend on remittances from migrants (Rössler *et al.*, 2010b). The region is characterized by a semi-arid to arid climate (Schulz & Judex, 2008). Traditional agricultural techniques allow coping with low average values of precipitation together with a high variability, by using a mixed system of irrigation agriculture and transhumant livestock grazing (Barrow & Hicham, 2000). Transhumant pastoralism mitigates variability in rainfall by mobility of herds on collective rangelands. The access to collective lands (*agdal*) used by tribal and intertribal groups as well as the opening and closing dates of pastures are fixed by the pastoralists at a local level (Rössler *et al.*, 2010a). After new livelihood options became available, 42% of households using formerly transhumant pastoralism have changed within the last decades towards the usage of sedentary flocks combined with the use of additional fodder from non-rangeland sources (Breuer, 2007b; Rachik, 2007; Davis, 2006). Within families, parts of the remittances from migrants are used to "subsidize" pastoral activities (Rössler *et al.*, 2010b).

Regional climate projections for the Drâa catchment differ greatly and indicate large uncertainty in the direction and magnitude of precipitation change (Sillmann & Roeckner, 2008; Born *et al.*, 2008; Huebener & Kerschgens, 2007). Those discrepancies lead to different projections of the regional risks of climate change in the region (Schilling *et al.*, 2011; Scheffran, 2009). Dryer conditions in the future, however, are a highly probable scenario and might substantially affect livelihood options within the socio-ecological system.

Hence, the research questions we are interested in our case study are:

a) What alternative livelihood strategies are probable to be chosen by the pastoralists provided that scarcity of precipitation makes it impossible to pursue the current strategy of transhumant pastoralism?
b) Is it possible to assign a certain probability to these alternative livelihood strategies or is contingency realistic?

c) Do the outcome and its predictability depend on the availability of other resources besides precipitation?

### *Interviews*

In our study region we interviewed 25 transhumant pastoralists in Berber language (*tajljeit*) by using interpreters. Interviews were based on a formalized questionnaire (see Appendix 1). Language skills and interview expertise of the interpreters made it possible to bridge the intercultural gap, concerning, for instance, problems like the meaning of "happiness".

Our interview partners belonged to tribal fractions of the Ait Toumert, Ait Zekri, Ait M'rauwn and Ait M'goun, who occupy comparable stripwise north-south oriented territories down from high mountain zones into the southern forelands. The main purpose of the interviews was to assess the resource requirements and expectations of the local land users associated with six alternative strategies. The considered strategies are based on Breuer (2007a) and are given with abbreviations in Table 1.

**Table 1: Strategies considered in the survey**

| Strategy | Short name |
|---|---|
| Traditional transhumance | TRAD |
| Sedentarity and localized pastoralism | SED |
| Commercialize pastoralism | COMM |
| Local engagement in tourism | TOUR |
| Working in urban centres (within Morocco) | CITIES |
| Working abroad | ABROAD |

*Traditional transhumance* (TRAD) is the livelihood strategy which all of our interview partners pursued at the time of the interview. In order to distinguish TRAD from other techniques of pastoralism we introduced the strategies *sedentarity and localized pastoralism* (SED) and *commercial pastoralism* (COMM).

As Rachik (2007) shows, SED appeared as an alternative livelihood strategy for transhumant pastoralists after the droughts in the 1970s. At that time, the government introduced forage supplements which enabled new options beyond TRAD.

A more recent development is the emergence of COMM as pastoral livelihood strategy in the region: It describes the use of additional fodder sources, for instance through financial help of migrants or by selling animals of large herds in a non-subsistence way. Furthermore, the financial resources created by COMM make it feasible for the herders to use trucks during times of fodder scarcity in order to displace the flock to remote areas (Breuer, 2007a).

The *local engagement in tourism* (TOUR) is a non-pastoral livelihood strategy which is getting more and more relevant in the region. Furthermore, *migration* is an important alternative livelihood strategy (Rössler *et al.*, 2010b), both *nationally to urban centres* (CITIES) and *internationally*, mostly to Europe (ABROAD).

In the interviews, the transhumant pastoralists were asked to establish a ranking of these strategies concerning their demand for resources and their potential for satisfying certain personal expectations of well-being such as prestige, happiness and income. A summary of the resource and expectation categories is shown in Table 2. The ranking of strategies was established through sequential comparison. As an example, the interview partners were asked which strategy they think of being most dependent on sufficient precipitation. When they answered for example TRAD, the following question was "which strategy requires less precipitation than TRAD?" and so on. It was possible for the interview partner to mention that several strategies do not significantly differ in their dependency on certain resources. The same scheme was applied to the expectations.

**Table 2: Types of resources and expectations considered**

| **Resources** | **Description** |
|---|---|
| Precipitation | Dependency of the strategy on rainfall |
| Capital | Capital needed for investments (at the beginning or during the course of the strategy) |
| Experience | Non-educational knowledge needed to perform this strategy |
| Education | Educational level (school) needed to perform this strategy |
| **Expectations** | |
| Prestige | Social position associated with the strategy |
| Income | Monetary income from this livelihood strategy |
| Happiness | Would you feel happy with using this strategy, regardless of income and prestige |

The quality of the interviews was mainly influenced in two ways: Firstly, we used five interviews to experiment and to ensure that our interview partners adequately understood our questions. Therefore, the first five interviews are of lower value than the latter ones. Secondly, the quality was influenced by the pastoralists' time and willingness to finish the interviews. At the end, among the 25 interviews performed, we consider 16 suitable for further evaluation (see Appendix 2).

## *Rationale of evaluation*

The method we use in this study does explicitly include the possibility of contingent decision making which enables us to identify indicators for non-deterministic behaviour. The distinctive element in this approach is that we use the concept of incomparability, which is a typical methodological element in partial order theory (e.g. (Bruggemann & Patil, 2010)).

To clarify our rationale, we start with a small example. Suppose we have two techniques or strategies A and B. As a result of an interview, both strategies are assigned rank scores for a set of two attributes r1 and r2 and are written as A{1,0} and B{0,1}. This notation means that strategy A is higher ranked concerning attribute r1 but strategy B is higher ranked by attribute r2. We do not use a weighting factor for the individual attributes in order to create a definite overall ranking, which would imply a subjective intervention by the analyst. Instead, we keep this incomparability and create a partial order with respect to the different attributes.

Now, let us assume a third strategy C exists. As result of the interview, we have C{2,2}. This means, C is ranked higher than A and B for both attributes and thus, can be definitely ranked higher than both. Figure 1 displays the partial order established from A, B and C graphically using the Hasse diagram technique (HDT, see (Bruggemann *et al.*, 2001; Bruggemann & Voigt, 2008)).

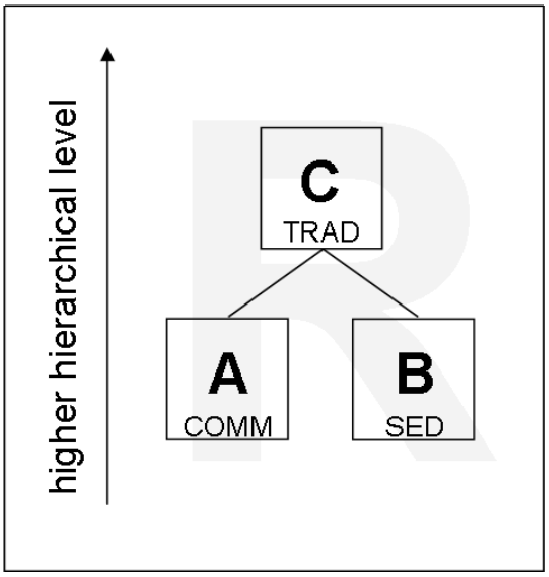


**Fig. 1** Partial order for ranking strategies A, B, and C with respect to resource attributes r1 and r2 (Resources-Partial Order: R-PO)

We want to combine two aspects in our investigation: On the one hand, we postulate that the strategies chosen by the land users are dependent on the availability of resources. This availability can be interpreted as a necessary condition: Only if fulfilled, the strategy can

be chosen at all. On the other hand, the available strategies are linked to certain subjective expectations of the transhumant pastoralists. For instance, a strategy which is feasible but not at all appreciated will only be chosen if there are no preferred alternatives available. Thus, as observed, expectations and norms dominate decisions on several alternative livelihood strategies (e.g. (Wilk, 2006; Crane, 2010; Nielsen & Reenberg, 2010)).

To address the two described factors of resources and expectations in our analysis, we separate partial orders of resources (R-PO) from partial orders of expectations (E-PO). This is done for every single interview.

We can now investigate what will happen if resource availability for a land user changes. To illustrate this, let us consider the small example from above. Assume strategies A, B, and C are the pastoral strategies COMM, SED, and TRAD, respectively. To pursue the strategies, the attributes r1 (experience) and r2 (precipitation) are necessary resources. Figure 1 displays the resource necessities by ordering A, B and C concerning to their attributes r1 and r2. Clearly, TRAD needs to most resources, SED and COMM are incomparable.

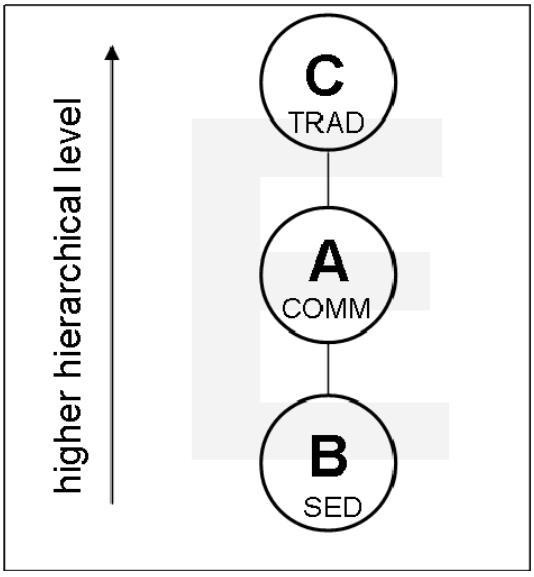


**Fig. 2** Partial order for ranking strategies A, B and C with respect to expectation attributes e1 and e2 (Expectations-Partial Order: E-PO)

Let us now assume two attributes for expectations (e1 and e2) which represent income and prestige. Suppose an expectation ranking of TRAD{1,1}, COMM{1,0} and SED{0,0}. That means both income and prestige are expected by the interviewed person to be lowest by pursuing SED. Let us further assume that there is no clear utility weighting between income and prestige and that the interviewed person is currently engaged in TRAD. Figure 2 shows that TRAD is preferred with regard to all expectations.

Let us now consider a situation where the amount of precipitation is decreased. The resulting amount of precipitation should be at least infinitesimally lower than the requirement of TRAD but higher than that for COMM and SED. By this way of reduction, we do not assume a certain threshold of reduction in rainfall. Instead, we investigate on a semi-quantitative basis what happens if a transhumant pastoralist will experience a reduction in rainfall which will force him to abandon the traditional livelihood strategy. What will be the most probable reaction of our interviewed person under this setting?

From the individual values for r1 and r2 in the R-PO we can conclude that both strategies COMM and SED are feasible alternatives. COMM and SED are therefore called *real successors* of TRAD because their critical attribute r2 (dependency on precipitation) is really smaller than that attribute for TRAD. All other attributes are equal or less. Next, we combine the outcome of the R-PO evaluation with the partial order of the expectations by assuming a priority of the latter (for a full mathematical analysis of combining partially ordered sets, see (Rademaker *et al.*, 2008)). Looking at the E-PO (Fig. 2), we find COMM preferred over SED. So the definite outcome of this situation will be that the interviewed person shifts to strategy COMM. We call such a situation *deterministic* because there is no alternative visible.

However, under a different structure of E-POs different outcomes are possible. Figure 3 illustrates two alternative E-POs. The left structure represents a case where options A and B are *equivalent* concerning their attributes e1 and e2, i.e. both attributes show the same level. Another situation is shown on the right structure of Figure 3: A and B are *incomparable*, because one expectation attribute of A is higher, one is less than the

attribute of B. We term both situations as *non-deterministic* because no clear preference can be given**.**

In standard rational decision making, non-deterministic situations are often resolved by introducing attribute weights and then forming an overall utility value which creates a definite ranking. However, creating such a ranking often reduces the objectivity of the result, especially for situations where it is hard to define an empirical weighting system. In our methodology, we avoid weighting and carry incomparability and equivalency throughout the evaluation. Even more: By explicitly considering the possibility of *choice*, we allow our investigated actors to entail *historical contingencies*. A non-deterministic situation, indicated by incomparability or equivalency in expectations, may therefore be regarded as a condensation nucleus for historical contingency. We consider this formal description of historical contingency from an *ex ante* perspective as the essential innovative element of our methodology.

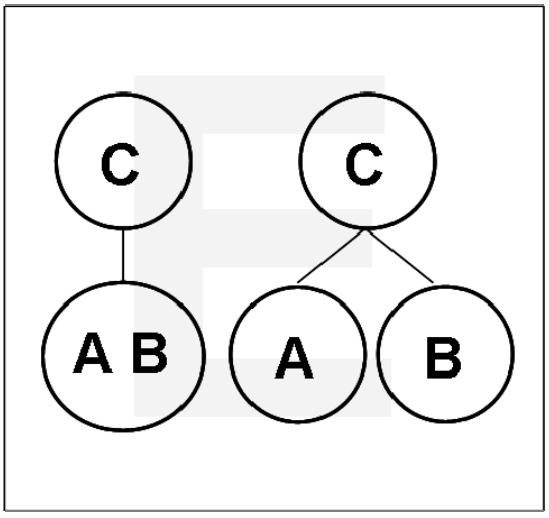


**Fig. 3** Partial order of alternative expectations for A and B equivalent (left), and for A and B incomparable (right) concerning attributes e1 and e2

The above example describes the general algorithm we use to evaluate interviews of *N* Moroccan pastoralists. For the E-PO, we include the concept of non-determinism and determinism. Incomparabilities in the R-PO are not relevant for the classification of results because expectation is dominant: For instance, if there are two strategies

incomparable concerning their resources, this poses no problem if one of them is preferred in E-PO. Only, if they are incomparable in the E-PO as well, they are treated as non-deterministic.

The only special case we have to consider is that there are no successors in E-PO at all, because either possible alternatives do not exist or we did not ask for them. Since our interviews do not reveal any information about possible missing strategies, we decided to count interviews without alternative options separately (addressed as "no alternative" in the final statistics).

After employing the above-described method, we obtain one of four possible outcomes for each individual interview:

a) no alternative strategy (no real successor in the R-PO) or

b) one or more real successor strategies concerning the R-PO with

- b1) definite ranking in the E- PO
- b2) equivalent ranking in the E- PO
- b3) incomparable ranking in the E- PO

Both options, b2) and b3) are regarded as non-deterministic because the agents of the system show no clear preference concerning alternative strategies.

The frequency of the considered strategies as outcome of the evaluations is counted and the occurrence relative to the number of interviews computed. Finally, for definite results, we calculate the *Shannon index* (SH, Shannon, 1948) to describe the distribution of outcomes [Equ.(1)].

$$SH = -\sum_i p_i \cdot \log_2 p_i \qquad with \quad p_i = \frac{n_i}{N} \tag{1}$$

where $p_i$ is the relative frequency of strategy $i$ within $N$ interviews ($n_i$ is the absolute occurrence). The SH is commonly used to characterize diversity of data and the Evenness of the Shannon index is the SH normalized by its possible maximum ($\log_2[N]$). The minimum evenness value of 0 indicates that only one strategy occurs in the results, whereas the maximum evenness value of 1 indicates an equal distribution of preferred strategies.

*Algorithm and application to our interviews*

The procedure of our algorithm can be summarized as follows:

1) There are *r* attributes of resources, *e* attributes of expectations and *i* strategies (see Tables 1 and 2)
2) Choose a strategy $i_x$ (the strategy, which is performed at the moment)
3) Choose a resource attribute $r_x$ of $i_x$, which will change in an evaluation scenario. Because $i_x$ is currently used, $r_x$ must be available in sufficient quantities for $i_x$. For instance, $r_x$ may be the estimated amount of precipitation per year. In the scenarios, $r_x$ decreases to levels insufficient to carry out $i_x$.
4) Select one of the *N* interviews
5) Use the R-PO to find all strategies *SR*, which are real successors for $i_x$ concerning the change in $r_x$. Because the new level of $r_x$ is too low for $i_x$, the remaining strategies must rely less on $r_x$. All other attributes of remaining strategies are equal or less.
6) Find the preferred strategy of *SR* in the E-PO. If *SR* is empty, terminate evaluation of the interview.
7) Repeat step 4) to 6) for all *N* interviews and apply Equ. (1) for definite outcomes.

If desired, increase the availability of one resource (e.g. capital) in the currently performed strategy such that other real successors than in the base scenario become feasible. Repeat step 1) to 7)

To clarify this algorithm, we now describe in detail the evaluation of one individual interview of our survey. This example corresponds to the R-PO and E-PO in Figure 4, where squares vertically represent the level of the considered resource and expectation attributes. The higher an "attribute tower", the higher a strategy is ranked by this attribute. TRAD is considered as currently pursued strategy, denoted as $i_x$ in the algorithm above. Precipitation *p* is considered as attribute $r_x$ from the algorithm above (grey squares in Fig. 4).

During the evaluation, precipitation is semi-quantitatively reduced to such an extent that TRAD becomes unfeasible for the transhumant pastoralist. As mentioned, the term “semi-quantitatively” indicates that we do not quantify a specific threshold in millimetres of rainfall. We only examine, what will happen if the pastoralist gives up TRAD due to a subjectively perceived scarcity of precipitation. Looking at the R-PO (Fig. 4, left), we find that SED and CITIES are real successors of TRAD under less precipitation, since the grey "tower" is smaller for SED and not existent at all for CITIES. COMM is not feasible because it requires the same ordinal level of precipitation as TRAD does and therefore it is not a real successor in this specific case. The evaluation of the interview additionally shows that ABROAD and TOUR would require a higher level of education from the interviewed person than currently available. Taking this result to the E-PO (Fig. 4, right), we find that SED is preferred, because it satisfies a higher level of prestige than CITIES. Hence, we have a definite outcome (SED), which is added to the final statistics of deterministic outcomes.

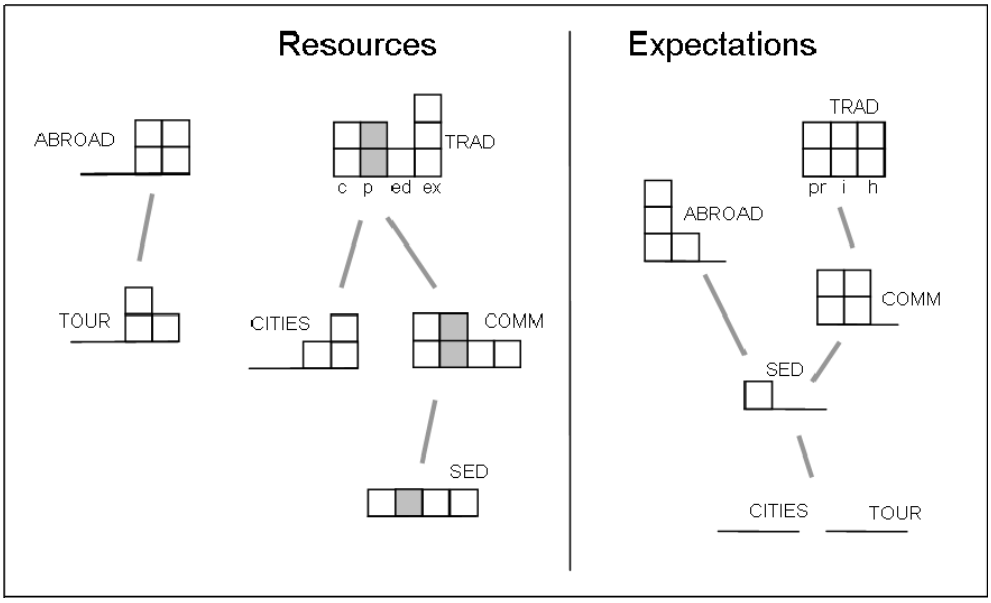


**Fig. 4** Resource-Partial Order (left) and Expectations-Partial Order (right) created from one of our interviews. Upper case terms denote livelihood strategies as given in Table 1. The squares vertically represent the attributes of resources and expectations indicated by lower case letters. Resources: c = capital; p = precipitation; ed = education; ex = experience; Expectations: pr = prestige; i = income; h = happiness (Table 2)

A non-deterministic outcome of our evaluation would have been achieved if both TOUR and CITIES would have been real successors to TRAD because these two strategies are equivalent in the E-PO. Such a result would have been added to the final statistics of equivalent outcomes.

For the scenario of less precipitation, one might also investigate, what would happen if the availability of several other resources is increased. For example, if the current level of available education (*ed*) would be increased by one unit (figuratively increasing the "tower" of this attribute in the currently pursued strategy TRAD), the real successors for TRAD would be SED, CITIES, ABROAD and TOUR (R-PO in Fig. 4). Taking this result to the dominating E-PO, one would find the strategy ABROAD as unique definite outcome, because it is ranked higher than all other real successors.

## Results

In our evaluation, we examine all 16 interviews on the impact of less precipitation (base scenario). To investigate possible policy options, we additionally examine the same precipitation scenario together with an experimentally higher availability of education and capital.

### *Decreased precipitation*

Decreasing the amount of precipitation yields a 38% probability in our model that a transhumant pastoralist will adopt SED as new livelihood strategy (Fig. 5). Together, for 56% of our investigated interviews we are able to assign definite outcomes. Other definite outcomes include CITIES with a probability of 13% and COMM with a probability of 6%.

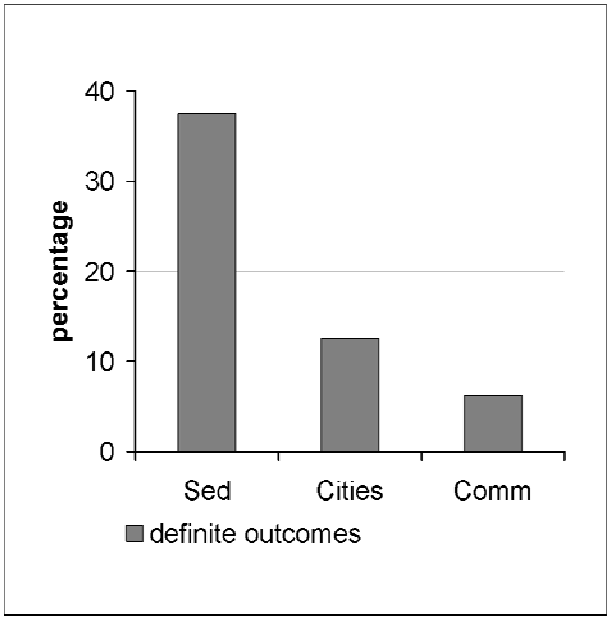


**Fig. 5** Occurrence of successor strategies as definite outcome. The availability of water was reduced to an extent that traditional transhumance is no longer feasible. Evenness = 0.39

A considerable proportion of the interviews (25%) did not lead to a definite successor livelihood strategy (Fig. 6). In these interviews, pastoralists turned out to be undecided or indifferent between SED, COMM, CITIES, TOUR and ABROAD. If these pastoralists were forced to abandon traditional transhumance, we would not be able to assign a probability for them choosing a certain successor strategy. We conclude from this that the real outcome for them under reduced precipitation is non-deterministic.

The evenness of the Shannon index in Fig. 6 equals 0.39 and implies that for the projected development SED is a clearly dominating successor strategy. For 19% of our interviews our method can not find any feasible alternative livelihood strategy.

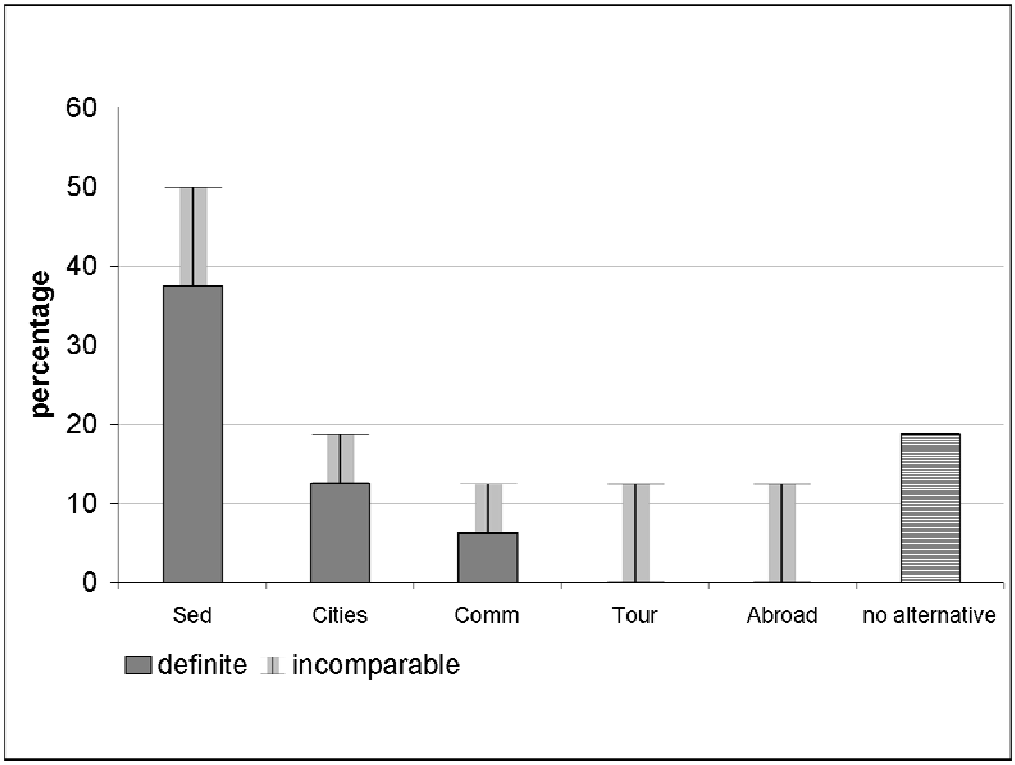


**Fig. 6** Abundance of alternative livelihood strategies for the case of *reduced precipitation* (n = 16). 25% of the interviews have non-deterministic outcomes

## *Enhanced capital and education*

In addition to the base scenario of reduced precipitation, we investigate the impacts of enhanced endowments of key resources such as the level of education and the availability of investment capital (for instance small loans). The effects of an enhanced availability of these resources are quite pronounced.

The case of an increased availability of capital is shown in Fig. 7. Under this assumption, the probability of adopting COMM as successor strategy increases from 6% in the base scenario to 25%. The probability of choosing SED decreases from 38% to 25%. Furthermore, the level of non-deterministic results increases to 31% and is 6% higher than in the base scenario. However, in contrast to the base scenario, there is only one pastoralist, who does not see a feasible successor strategy at all under the considered circumstances.

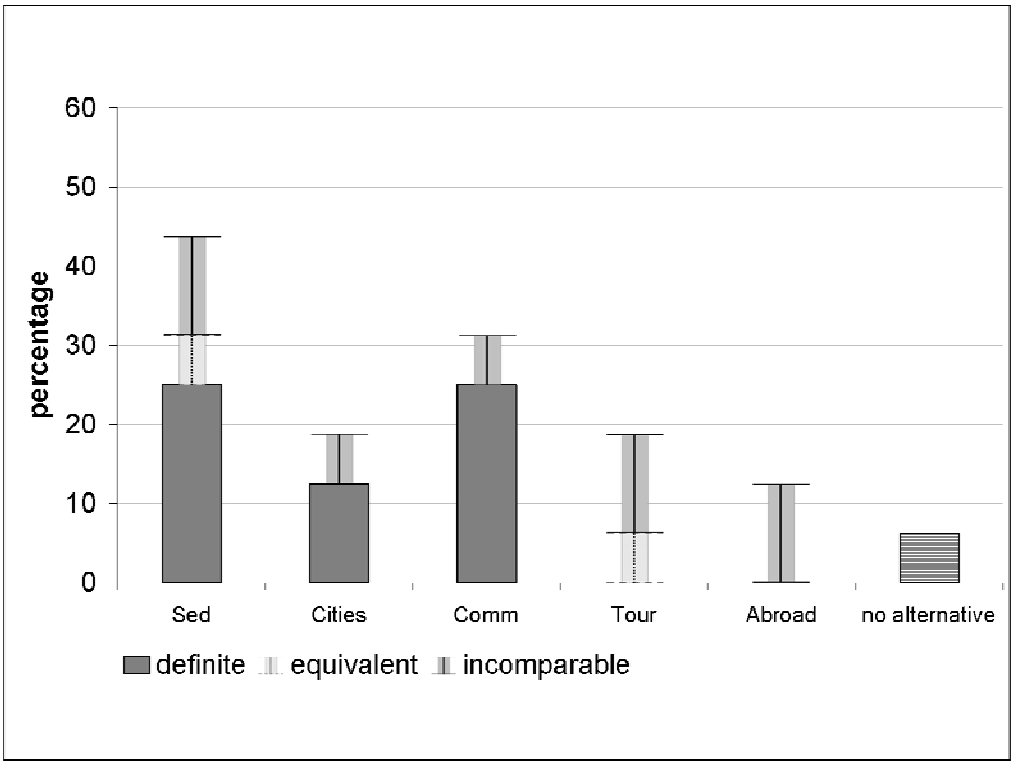


**Fig. 7** Abundance of alternative livelihood strategies for *higher availability of capital* and reduced precipitation (n = 16). 31% of the interviews show non-deterministic outcomes. Evenness = 0.45

Figure 8 shows the results for the combination of reduced precipitation and a higher level of education. In this scenario setup only CITIES, COMM, and ABROAD are within the set of definite strategies with a combined probability of 25%. The majority of results (56%) have non-deterministic outcomes where probabilities cannot be assigned. As in the base scenario, for 19% of the transhumant pastoralists an alternative livelihood cannot be found at all.

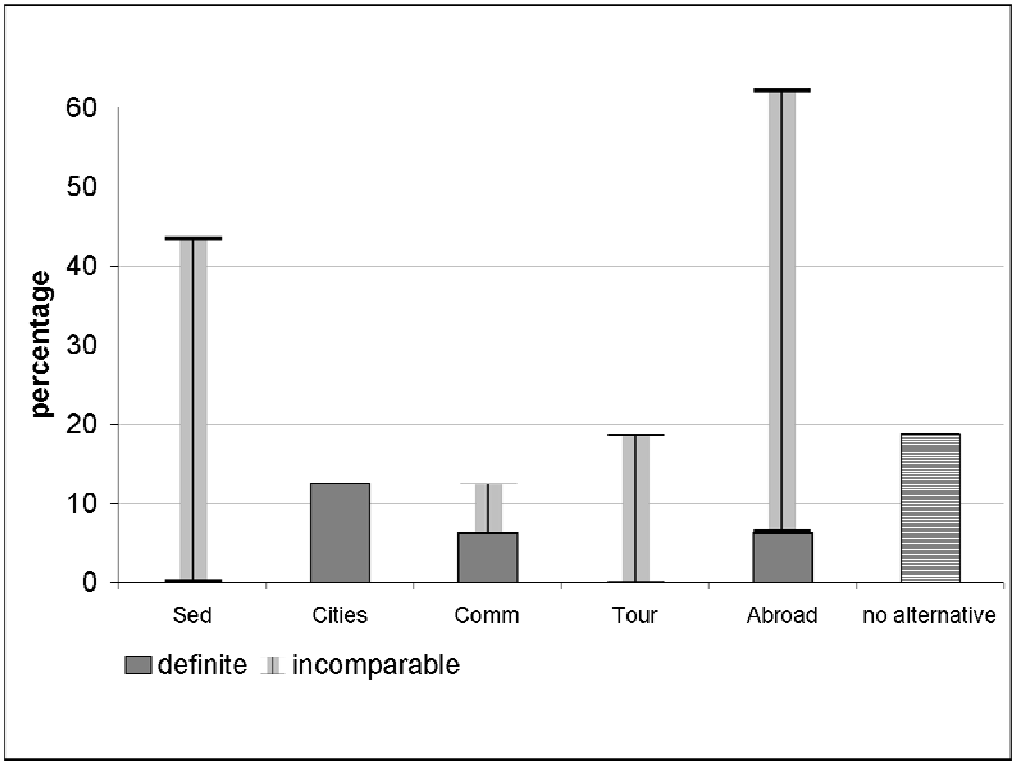


**Fig. 8** Abundance of alternative livelihood strategies for a *higher level of education* and reduced precipitation (n = 16). 56 % of the interviews have non-deterministic results. Evenness = 0.75

Finally, we analyze reduced precipitation together with increases in both, education and availability of capital. Results are shown in Fig. 9. Obviously, the values in Fig. 9 are not just a simple linear combination of the previous results. The availability of both resources makes it now feasible that four livelihood strategies are considered as definite alternative strategies. The resulting diversity (Evenness = 0.58) is higher than for all previous scenarios. Under the combined setup, only 6% of the interviewed pastoralists would choose SED as alternative. This value for SED is in clear contrast to 37% in the base scenario (Fig. 6) and 28% in the increased capital scenario (Fig. 7). Similarly as in the increased capital scenario, 25% of answers indicate commercial pastoralism as definite successor strategy. Still, 43% of outcomes are unpredictable. Only for one interview we can not find a feasible successor livelihood strategy.

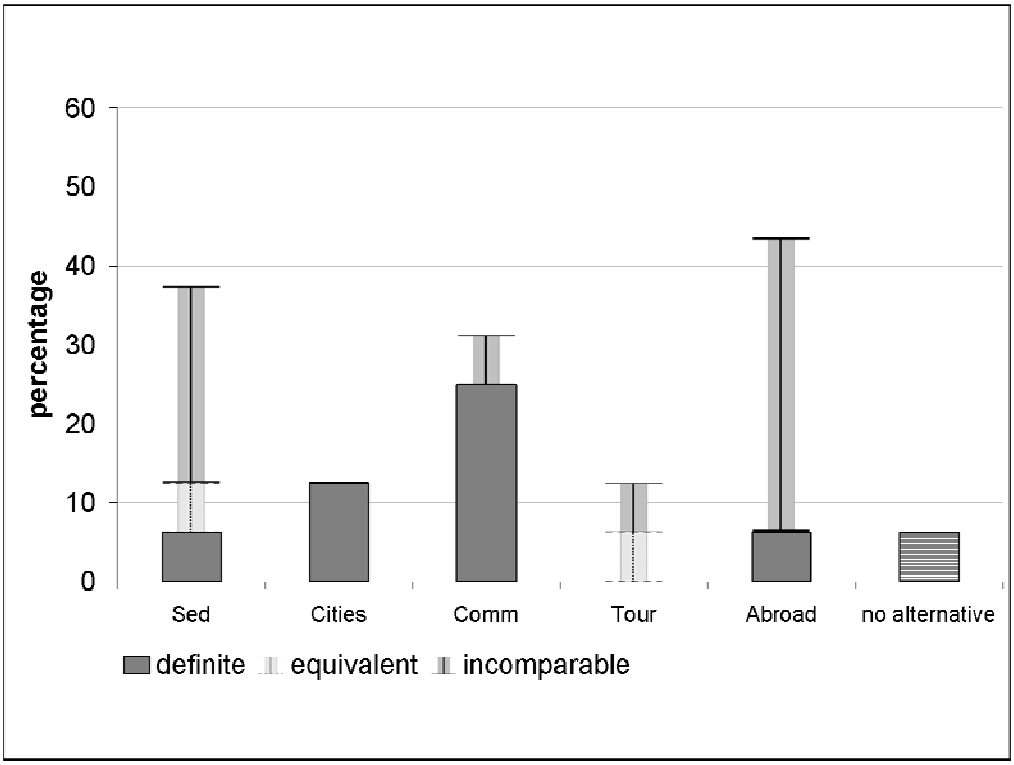


**Fig. 9** Abundance of alternative livelihood strategies for *higher availability of education and capital,* and reduced precipitation (n = 16). 43 % of the interviews have non-deterministic results. Evenness = 0.58

## Discussion

### *Methodology*

The presented analysis may be scrutinized in a fourfold manner: Firstly, one might ask what is new and cannot or has not been examined with existing methods? Secondly, are there explicit or implicit assumptions hidden behind the method? Thirdly, how to validate the model? Fourthly, are there non-trivial insights generated through the results?

Concerning the first point, the novel aspect of our method is to distinguish between predictable and unpredictable outcomes in mathematical formal terms and describing possible points of contingency *ex ante*. Therewith, we bridge concepts of natural and social sciences. We believe that existing multi-criteria analyses (MCA) mostly aim at a final, objectively clear ranking (e.g. Brans & Vincke, 1985; Geldermann & Rentz, 2001; Strassert & Prato, 2002; Koo & O'Connell, 2006) but do not distinguish between

deterministic and non-deterministic structures. Instead of describing a ranking of different options like other MCA's do, we elaborate a statement about future decision pathways. Within the same setup, we investigate possibilities of altering the outcome of the analysis and the level of predictability by altered resource endowments. Thus, our analysis based on simple elements of the theory of partially ordered sets aims much more at system properties than traditional MCA. In contrast to a survey, where the alternatives used under certain conditions are directly solicited, our model leaves the option of later choices and allows to investigate easily which attributes play an important role in determining (or un-determining) the outcome.

Concerning the second question of hidden assumptions, firstly, we suppose that there are no trade-offs possible between the chosen attributes like *precipitation* and *capital*. Nonetheless, we tried to capture only those attributes of resources and expectations, which are not easily replaced by one another. For example, a sedentary farmer could "replace" *water* by *capital* by installing a motorized water pump. For a nomadic pastoralist moving through vast areas, this is not suitable. We tried to capture possible trade-offs as discrete strategies. For instance, the case of trading livestock for additional fodder to a higher degree than usual is addressed in COMM.

As second assumption, we consider the interviewed pastoralists to have a profound knowledge about their current livelihood strategy as well as their alternatives, which might be imperfect. Our model may therefore only reveal the land users opinions and hopes. However, studies on human decision making (Klein, 1999; Wilk, 2006) and studies of observed choices of adaptation strategies from other pastoralist societies (Nielsen & Reenberg, 2010; Crane, 2010; Pedersen & Benjaminsen, 2008) suggest that subjective opinions often affect real decisions more than scientifically measured parameters.

Studies from social psychology and environmental sciences suggest further that expectations and perceptions of human beings may significantly change over time (Pinnegar & Engelhard, 2008; Welzer, 2009). The insights provided by our study are therefore primarily based on present conditions and perceptions and can only be considered as a snapshot of the actual situation. Possible dynamic feedbacks, for instance via impacts of successor strategies on land scarcity are, if at all, only included implicitly.

If at some point pastoralists would change their livelihood strategy, their perceptions and expectations for this livelihood strategy will change, since a pursued livelihood is positively biased against alternatives due to psychologically motivated self-affirmation (Steele, 1988). Hence, our E-PO describes only the current situation and should be used only for assessing the very next step of the development of the socio-ecological system.

Besides these two major assumptions, the robustness of our study is limited by the small number of considered interviews. However, a statistical re-sampling analysis (Cirincione & Gurrieri, 1997) shows that a maximum error in our results of 15 to 20% is possible but only in the case of really extreme bimodal distributions of preferred strategies by the population. In realistic cases the error of our analysis should be much lower since we interviewed a quite homogenous population.

Concerning the third question, the validation of our model poses a difficult task. Our analysis is locally and temporally very specific - the answers of transhumant pastoralists would have been different 30 years ago and are likely different in other regions. Thus, our model can be validated on its own by observing the future development of livelihood strategies of transhumant pastoralists in the Drâa basin while simultaneously observing changes in precipitation regimes.

Comparing our model to similar studies which use different methods is another option for validation (Stirling, 2006): It has been shown that beginning from the droughts in the 70's, SED became the dominant livelihood strategy for transhumant pastoralists (Breuer, 2007b; Davis, 2006). Our results are therefore confirmed from a different perspective, although these studies take up a historical perspective and our study is directed towards future developments.

Another point on validation concerns the treatment of non-deterministic results. Popper shows that the falsification of our definite results is possible in principle if a sufficiently large number of transhumant pastoralists is considered (Popper, 1959). The model would be falsified, for example, if in the near future a substantial number of nomads would abandon their traditional livelihood and nobody would turn to SED but all would leave the country (ABROAD; see Fig. 6). However, falsification becomes more difficult when we include the non-deterministic results. Our non-deterministic results are not entirely what Popper called chance, which he defined as "our knowledge does not suffice for

prediction" (Popper, 1959, p. 69). Instead, it can be seen in a Bayesian perspective as a degree of plausibility of expected outcomes (Jaynes, 2003) or an indicator of deep uncertainty (Walker *et al.*, 2010).

For example, in the base scenario, we find a range of 12.5% of non-deterministic results concerning SED for all nomads abandoning their traditional livelihood. The non-deterministic results can be added to the deterministic ones and therefore, the overall frequency of SED as outcome covers a range from 37.5% to 50% (see Fig. 6 and Table 3). Since we are able to put a number on that possible deviation, we are convinced it represents a useful non-trivial insight.

**Table 3: Frequency of SED as preferred successor strategy for different scenarios**

| Scenario | definite abundance | maximum abundance (definite + non-deterministic results) |
|---|---|---|
| base scenario | 38 % | 50 % |
| access to capital | 25 % | 48 % |
| access to education | 0 % | 44 % |
| capital + education | 6 % | 38 % |

## *Insights and applications*

While unpredictabilities remain, at least 38% of the interviewed nomads would definitely opt for SED if precipitation decreases below the minimum threshold for traditional transhumance. This result may also reflect the development of different attitudes towards sedentarity on the part of nomads within the past 40 years (Rachik, 2007). However, SED is not necessarily a secure alternative since an increasing number of sedentary people in the Drâa region increases pressure on available arable land and ground water resources (Kirscht, 2008). Therefore, the real and perceived benefits of SED are likely to decrease.

If social planners would like to avoid a development which favours mainly SED, our model results can help to identify possible policy interventions: Considering the definite outcomes, a better access to education substantially decreases SED as preferred livelihood successor strategy with respect to TRAD (Table 3). However, a considerable degree of uncertainty is associated with that outcome. In an extreme case, non-

deterministic outcomes for this scenario could turn into reality such that overall 44% of the transhumant pastoralists finally opt for SED. By considering that implication, our model shows that the scenario with a higher access to capital and education at the same time might be a more secure option. In this 'capital and education' scenario, only 38% would opt for SED as alternative in the most extreme case (non-deterministic and definite outcomes added) and only 6% would opt for it definitely. Additionally, four out of five livelihood options in this scenario would be definitely chosen by some pastoralists indicating a more diverse set of possible strategies (Fig. 9).

Since our model only uses ordinal ranking, we cannot estimate how much capital should be invested in education in order to stimulate this development. However, we can say that if access to education and capital at the same time is increased relative to the current level, the socio-ecological system will move away from SED as a dominant alternative strategy.

Our method can be applied primarily to investigate social and socio-ecological systems, where human decisions represent a major influencing factor for future pathways. In many cases, it is highly uncertain which technological options or alternative livelihoods will be chosen by human actors under altered conditions. It has been shown repeatedly that human expectations and values heavily influence pathways of socio-ecological systems, even if the same environmental boundary conditions are considered ( Wilk, 2006; Thornton *et al.*, 2007; Nielsen & Reenberg, 2010; Crane, 2010). Human behaviour therefore is often perceived as unpredictable and many development projects have failed due to overestimating predictable capacities of scientific analyses (Pedersen & Benjaminsen, 2008; Scott, 1998). Our method, which needs only a little bit more effort like a conventional survey, offers an adequate measure for better assessing predictability of human decisions beforehand.

## Conclusions

We present a novel method to assess the predictability of future decision pathways of socio-ecological systems in a mathematically formalized way. For the application to semi-arid Morocco, we use 16 interviews of transhumant pastoralists. Due to the relatively small number of interviews, the explanatory power of our results might be

limited. However, we can show that there are livelihood strategies which are definitely preferred over others by the pastoralists and that many pastoralists are undecided between possible alternatives. This indicates a relevant possibility of a contingent development in our investigated socio-ecological system for the case that precipitation will force the pastoralists giving up their traditional livelihood strategy.

In our analysis, we use the concept of historical contingency in a new manner in order to determine whether a future development of a system is to a certain degree predictable or not. We assume that unclear preferences with respect to possible alternatives in a decision situation are responsible for unpredictable human behaviour. Since humans are the key agents in most socio-ecological systems, we relate the predictability of the system to the predictability of human decision making. Using standardized interviews, in combination with simple elements of partial order theory, we show how clear preferences of our key agents can be separated from unclear ones. This allows us to deduce levels of predictability for a hypothesized future decision situation. Hence, our study shows how the important concept of contingency can be given a solid mathematical basis.

## Acknowledgements

First of all, we want to thank all of our interview partners whose open-hearted hospitality we greatly appreciated. Second, we would like to thank the interpreters Redouane Ouhmouch and Abdelaziz Labdi for their professional work. We thank two anonymous reviewers and Jochem Marotzke, Dallas Murphy, and several students of the IMPRS-ESM Hamburg for their comments, which substantially improved the explanatory power of this paper. From Michael Hauhs we picked up the idea of separating determinism from non-determinism. We thank the BIOTA-Maroc project team, whose expertise and infrastructure we used in order to perform this study (German Federal Ministry of Education and Research, Förderkennzeichen 01 LC 0601A).

## References


Barrow CJ, Hicham H (2000) Two complimentary and integrated land uses of the western High Atlas Mountains, Morocco: the potential for sustainable rural livelihoods. *Applied Geography* **20** 369-394.

Bennett A, Elman C (2006) Complex causal relations and case study methods: the example of path dependence. *Political Analysis* **14** 250-267.

Berkes F (1999) Sacred Ecology - Traditional ecological knowledge and resource management. Taylor & Francis, Philadelphia, 232 pp.

Beyer J (2010) The same or not the same - on the variety of mechanisms of path dependence. *International Journal of Social Sciences* **5** 1-11.

Born K, Piecha K, Fink A (2008) Shifting Climate Zones in the Northwestern Maghreb. In: IMPETUS Atlas Marokko - Research Results 2000-2007 (eds. Schulz O, Judex M), IMPETUS Project, Köln/Cologne.

Brans JP, Vincke PH (1985) A Preference Ranking Organization Method - (the Promethee Method for Multiple Criteria Decision-Making). *Management Science* **31** 647-656.

Breuer I (2007a) Livelihood security and mobility in the high atlas mountains. In: Pastoral Marocco - Globalizing Scapes of Mobility and Insecurity (eds. Gertel J, Breuer I), pp. 165-179. Reichert, Wiesbaden.

Breuer I (2007b) Marketing from the margins: the Ilmichan pastoralists of the Pre-Saharra. In: Pastoral Marocco - Globalizing Scapes of Mobility and Insecurity (eds. Gertel J, Breuer I), pp. 117-132. Reichert, Wiesbaden.

Bruggemann R, Halfon E, Welzl G, Voigt K, Steinberg CEW (2001) Applying the concept of partially ordered sets on the ranking of near-shore sediments by a battery of tests. *Journal of Chemical Information and Computer Sciences* **41** 918-925.

Bruggemann R, Patil G (2010) Multicriteria priorization and partial order in environmental sciences. *Environ.and Ecological Statistics* **17** 383-410.

Bruggemann R, Voigt K (2008) Basic Principles of Hasse Diagram Technique in Chemistry. *Combinatorial Chemistry & High Throughput Screening* **11** 756-769.

Cirincione C, Gurrieri GA (1997) Research methodology - Computer-intensive methods in the social sciences. *Social Science Computer Review* **15** 83-97.

Crane TA (2010) Of Models and Meanings: Cultural Resilience in Social-Ecological Systems. *Ecology and Society* **15** .

Davis DK (2006) Neoliberalism, environmentalism, and agricultural restructuring in Morocco. *Geographical Journal* **172** 88-105.

Geldermann J, Rentz O (2001) Integrated technique assessment with imprecise information as a support for the identification of best available techniques (BAT). *Or Spektrum* **23** 137-157.

Goldstone JA (1998) Initial conditions, general laws, path dependence, and explanation in historical sociology. *American Journal of Sociology* **104** 829-845.

Hauhs M, Lange H (2008) Classification of Runoff in Headwater Catchments: A Physical Problem? *Geography Compass* **2** 235-254.

Huebener H, Kerschgens M (2007) Downscaling of current and future rainfall climatologies for southern Morocco. Part II: Climate change signals. *International Journal of Climatology* **27** 1065-1073.

Jaynes ET (2003) Probability Theory - The Logic of Science. Cambridge University Press, Cambridge, 727 pp.

Kirscht H (2008) Agricultural strategies: Irrigation management, risk diversion and crop rotation in Tichki. In: IMPETUS Atlas Marokko - Research Results 2000-2007 (eds. Schulz O, Judex M), pp. 73-74. IMPETUS Project, Köln/Cologne.

Klein G (1999) Sources of Power - how people make decisions. The MIT press, Cambridge, 330 pp.

Koo BK, O'Connell PE (2006) An integrated modelling and multicriteria analysis approach to managing nitrate diffuse pollution: 1. Framework and methodology. *Science of the Total Environment* **359** 1-16.

Lorenz E (1963) Deterministic nonperiodic flow. *Journal of the atmospheric science* **20** 130-141.

Mahoney J (2000) Path dependence in historical sociology. *Theory and Society* **29** 507-548.

Nielsen JO, Reenberg A (2010) Cultural barriers to climate change adaptation: A case study from Northern Burkina Faso. *Global Environmental Change-Human and Policy Dimensions* **20** 142-152.

Pedersen J, Benjaminsen TA (2008) One leg or two? Food security and pastoralism in the northern Sahel. *Human Ecology* **36** 43-57.

Pinnegar JK, Engelhard GH (2008) The 'shifting baseline' phenomenon: a global perspective. *Reviews in Fish Biology and Fisheries* **18** 1-16.

Popper K (1959) The logic of scientific discovery. Routledge, London, 544 pp.

Rachik H (2007) Nomads: But how? In: Pastoral Marocco - Globalizing Scapes of Mobility and Insecurity (eds. Gertel J, Breuer I), pp. 211-252. Reichert, Wiesbaden.

Rademaker M, De Baets B, De Meyer H (2008) New Operations for Informative Combination of Two Partial Order Relations with Illustrations on Pollution Data. *Combinatorial Chemistry & High Throughput Screening* **11** 745-755.

Regan HM, Colyvan M, Burgman MA (2002) A taxonomy and treatment of uncertainty for ecology and conservation biology. *Ecological Applications* **12** 618-628.

Rosen R (1991) Life itself - a comprehensive inquire into the nature, origin, and fabrication of life. Columbia University Press, New York, 285 pp.

Rössler M, Kirscht H, Rademacher C, Platt S (2010a) Demographic development in Southern Morocco: Migration, urbanization,and the role of institutions in resource management. In: Impacts of Global Change on the Hydrological Cycle in West and Northwest Africa (eds. Speth P, Christoph M, Diekkrüger B), Springer, Heidelberg, Germany.

Rössler M, Kirscht H, Rademacher C, Platt S, Kemmerling B, Linstädter A (2010b) Migration and resource management in the Drâa Valley, Southern Morocco. In: Impacts of Global Change on the Hydrological Cycle in West and Northwest Africa (eds. Speth P, Christoph M, Diekkrüger B), Springer, Heidelberg, Germany.

Scheffran J (2009) The gathering storm - is Climate Change a security threat? *Security Index* **2** 21-31.

Schilling J, Freier K, Hertig E, Scheffran J (2011) Climate change, vulnerability and adaptation in North Africa with focus on Morocco. *Regional Environmental Change (submitted)* .

Schulz O, Judex M (2008) Impetus Atlas Morocco: Research results 2000-2007. Department of Geography, University of Bonn, Bonn, Germany, 79 pp.

Scott J (1998) Seeing like a state: How certain schemes to improve the human condition have failed. Yale University Press, New Haven, 464 pp.

Shannon CE (1948) A mathematical theory of communication. *The Bell System Technical Journal* **27** 379-423.

Sillmann J, Roeckner E (2008) Indices for extreme events in projections of anthropogenic climate change. *Climatic Change* **86** 83-104.

Steele CM (1988) The psychology of self-affirmation: Sustaining the integrity of the self. In: Advances in experimental social psychology, Vol. 21 (ed. Berkowitz L), pp. 261-302. Academic press, New York.

Stirling A (2006) Analysis, participation and power: justification and closure in participatory multi-criteria analysis. *Land Use Policy* **23** 95-107.

Strassert G, Prato T (2002) Selecting farming systems using a new multiple criteria decision model: the balancing and ranking method. *Ecological Economics* **40** 269-277.

Thornton PK, Boone RB, Galvin KA, BurnSilver SB, Waithaka MM, Kuyiah J, Karanja S, Gonzalez-Estrada E, Herrero M (2007) Coping strategies in livestock-dependent households in east and southern Africa: A synthesis of four case studies. *Human Ecology* **35** 461-476.

Walker WE, Marchau VAWJ, Swanson D (2010) Addressing deep uncertainty using adaptive policies: Introduction to section 2. *Technological Forecasting and Social Change* **77** 917-923.

Welzer H (2009) Klimakriege - Wofür im 21. Jahrhundert getötet wird. Fischer Taschenbuch Verlag, Frankfurt am Main/Germany, 335 pp.

Wilk R (2006) "But the young men don't want to farm any more": Political ecology and consumer culture in Belize. In: Reimagining Political Ecology (eds. Biersack A, Greenberg J), pp. 149-170. Duke University Press, Durham.

**Formatted:** Tabs: 0 cm, Left