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From social-enquiry to decision support tools: towards an integrative method in the mediterranean rural environment

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Policy-relevant approaches to assessing land-use change must be based upon a number of transdisciplinary mechanisms. This approach demands a number of skills—social enquiry, modelling and soft complex systems thinking, which are necessary to facilitate an effective cross-disciplinary dialogue. Underpinning the development of these transdisciplinary skills, and the acceptance of systems as complex and subject to multiple interpretations, is the need to move away from the desire to predict and towards enhancing the capacity to adapt. In terms of methodology, this means the exploration of a range of possible futures rather than the anticipation of any specific future path.

In this paper, we present an example of the 'Integrative Method' in the context of Mediterranean desertification. The basis of this work has been the need to include stakeholders in the research, planning and implementation of policies and a willingness to step beyond disciplinary paradigms towards an integrative and transdisciplinary approach. This requires an approach that is grounded in systemic thinking, social enquiry, and the need explore the future through a range of conceptual and mathematical models which are accessible to policy makers.

Keywords: multidisciplinary; integrative research; policy relevant, modelling; social enquiry; decision support tools; mediterranean

Introduction

Policy-relevant approaches to assessing land-use change must be based upon a number of transdisciplinary mechanisms for characterizing situations and phenomena that are seen to constitute a problem at the local level (van der Leeuw, 1998). They are driven by issues as they are perceived in the 'real' world and emphasize a number of skills—social enquiry, modelling and soft complex systems thinking—necessary to facilitate effective cross-disciplinary dialogue. Integrative research, as we conceive it,

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requires that representatives of single disciplines retain their distinctive and consistent frames of reference, while establishing an effective framework for communicating with each other. This is particularly important with disciplines that focus upon natural and social phenomena as discrete and independent, without providing us with handles to interpret the interaction between them.

Underpinning the development of these transdisciplinary skills, and the acceptance of systems as complex and subject to multiple interpretations, is the need to move away from prediction, and towards enhancing the capacity to adapt (McLain and Lee, 1996). In terms of methodology, this means the exploration of a range of possible futures rather than the anticipation of any specific future path. This has important implications for how we interpret sustainability in that it encourages us to look towards viable paths rather than end states. While science and politics are part of the same complex processes their responsibilities must remain clear and distinct. Decisions about uncertain futures should not be based upon the impression of scientific certainty, and responsibility for those decisions must lie within the political arena.

If we accept that bio-physical, socio-economic, technological and policy processes are inextricably linked, what 'transdisciplinary' mechanisms can help disciplines communicate in a way that enhances our collective insight but does not dilute the expertise within the disciplines (Lemon & Longhurst, 1996; Lemon, 1999*a*, 1999*b*)? The nature of these systemic interactions questions our ability to 'predict', and in so doing highlights the need to explore potential futures and the associated adaptive responses. How can we aid in the facilitation of this process in a way that is accessible and meaningful? Moreover, the definition and implementation of policy is invariably top-down, a feature that is often the result of 'standardizing' what may be multiple and diverse rural environments. The same conditions, if they ever exist, will be interpreted differently by stakeholders in different locations. There are also multiple stakeholders within single locations with different perceptions of what constitute issues and those perceptions may well change over time in response to acquired knowledge (Green & Lemon, 1996*a*, Green *et al.*, 1997; Lemon & Blatsou, 1999*a*).

One vehicle for this acquired knowledge might be the dissemination, (mis)interpretation of, and response to science (Gibbons *et al.*, 1999). The consideration of possible futures inevitably, or at least invariably, changes the way we interpret the present. This is of fundamental significance for the way we consider issues of sustainability. Even if it were possible to 'sight' a sustainable future, that very sighting would instigate responses that may deny its ever being reached (Allen, 1990; Eden & Ackerman, 1998).

To draw upon contemporary jargon, our approach must be 'inclusive' and incorporate the 'messiness' and diversity of the local (Checkland, 1981). In other words, we need to move from the disaggregate to the aggregate and not vice versa. It is of course unrealistic to suggest that we can undertake unique and comprehensive studies of all locations at a multitude of scales. The role of an integrative and policy-relevant method must be to provide a comparative framework that is grounded in local case studies but can be applied to other locations in a quasi-generic fashion (Newby, 1992).

Integrative research

This paper expands on each of these issues through the example of an integrative method that has been developed in the Argolid, Greece and the Marina Baixa, Spain. It will suggest three broad transdisciplinary skills sets that are essential for managing the rural environment in an inclusive and integrative manner (Lemon & Longhurst, 1996). These are firstly, the ability and willingness to think systemically and to question premature attempts to simplify issues from single disciplinary perspectives. Secondly, we need to know the range of stakeholders and to be informed as to how they perceive their environment and the potential responses to changes within it. We need to be able to observe and listen. Finally, we need to be able to generate potential futures for exploration rather than prediction. We cannot predict the future but we need to learn from it (McLain & Lee,1996; Portugali, 2000); herein lies the role for conceptual and mathematical modelling, and the development of interactive decision support tools.

Research towards a sustainable systems framework requires links to be made between scientific, sociological and socio-economic theory (Newby, 1992), and for information to be presented in a manner which is directly relevant to the policy formulation and decision-making process. Such an approach inevitably raises questions about the way in which research should be designed so that information from both the natural environment and the social, economic and cultural systems can be combined. Research frameworks need to demonstrate the connections between a variety of investigative activities and policy. In terms of decision making, these connections are as important as the research activities themselves. A number of key issues can therefore be identified as central to integrative method and policy-relevant research:

- There are significant problems with obtaining data at a sufficient level of definition to be useful but at the same time capable of providing an insight into the variation within the system of study, both through time and across space.
- There is a need to improve our understanding about how different social structures affect and are affected by the natural environment (socio-natural inter-relationships).
- To be policy relevant these two issues must be represented in an interactive format which can inform about the range of possible futures that might emerge from the influence of different policy instruments (Decision Support Tools).

These three issues provide the underlying structure of the integrative method which has been developed within the context of a number of EU research programmes (Winder & van der Leeuw, 1997; van der Leeuw, 1998*b*, Lemon, 1999*a*, 1999*b*; Lemon *et al.*, 1999; Oxley *et al.,* 2002). Integration in this context is achieved via a series of interfaces (Park and Seaton, 1995) that link the concept of sustainability to information that is relevant to policy. These interfaces are shown in Fig. 1, and represent:

(i) Interpretation of the concept of sustainability at an ecological level.
(ii) Linking of ecological processes to attitudes and behaviours of agents.
(iii) Linking actions and perceptions of agents of change to policy issues.

Systemic thinking

Dickens (1992) and Latour (1993), amongst others, question the separation of human culture from nature and from the physical environment; all humans are actors but not all actors are human. The culture of a locality is not only manifest through the perceptions, beliefs, norms, relationships and actions of humans but through the 'hardware' and structures that constitute its physical and institutional presence.

The juxtaposition of natural, physical, socio-cultural and economic phenomena cannot be understood from the perspective of hydrology, agronomy, soil science,

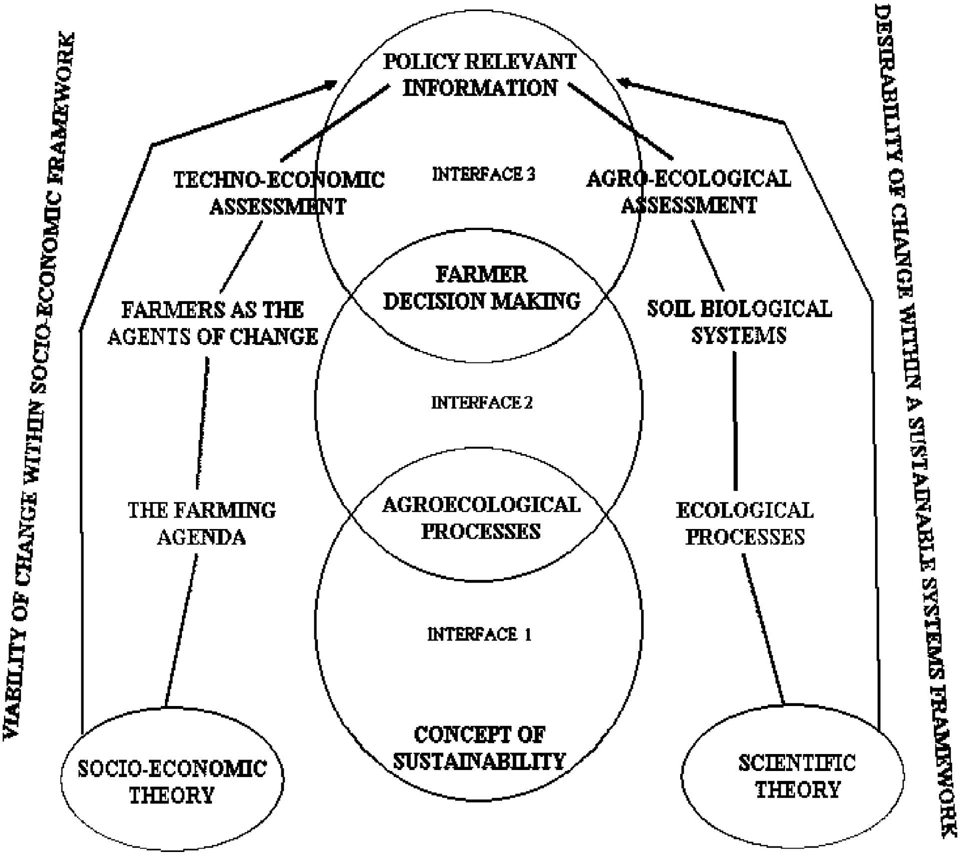


Figure 1. A representation of the social, scientific and natural processes involved in integrative research and sustainable agriculture, highlighting the key interfaces linking the concept of sustainability to policy relevant information (from Park & Seaton, 1995).

sociology, economics, engineering or meteorology. Each of these disciplines has an obvious role to play, but initially this must be defined through, and fed into the broader picture. It is the relationships *between* phenomena that are of interest and these seldom fall within disciplinary boundaries (Cilliers, 1998).

A response to the messiness of complex systems has often been to clean them up through the adoption of well-defined and clear disciplinary perspectives and procedures. One feature of this approach has been to acquire data at high levels of resolution that initially contributes very little to our understanding of the wider picture. Ongoing hydrological studies through the 1980s and 1990s provided useful and in-depth information about a restricted number of very localized sites in and around the Argolid Plain in the Peloponnesse, Greece. Over 200 interviews with farmers (approximately 10% of farmers in the area) gave information about water use and quality across the entire study area. Much of the land had been passed down and as such information could also be established about the same phenomena over two to three generations. While this data were subject to the vagaries of individual and collective memory, and on occasions to lack of trust and artistic license, it did provide an informed overview of the qualitative and quantitative hydrological trajectories.

The question of resolution is inextricably linked to that of scale and the bounding of our system of interest (Green *et al.*, 1998). This has obvious methodological implications. For example, can the response of one tree to excessive salts provide an insight into how salination will affect a plantation? Alternatively, will one farmer respond in a particular way to a decision issue once the normative response of his or her peer group becomes evident? Figure 2 provides a schematic representation of how geographical scale can indicate the need for different disciplinary contributions.

This example of the Argolid is obviously multi-scalar and highlights a number of classification issues in terms of scale that are relevant to how we look at natural–human interactions in general. In the context of time, we need to have some feel, not only for the duration over which a process takes place (e.g. the length of a drought in months or years, or an extreme rain event in minutes), but for the dynamic of that process and its inter-relationships with other phenomena. For example, heavy frosts in combination with plant disease destroyed many of the areas' lemon plantations in the late 1960s. Either of these, in isolation, might have decimated the annual crop but not the plants.

In terms of farming decisions, the use of water to irrigate a field will have a limited impact on the condition of an aquifer. The converse of course may not apply and the aquifer will determine the ability of an individual to irrigate. Collectively, however, the impact of irrigation decisions may well affect the condition of an aquifer and thereby the ability of the individual farmers to irrigate in the future. This in turn may lead the farmers to depart from their individualistic mode of behaviour and to form a collective response in terms of joint investment in expensive remedial technologies.

In these 'simple' examples it is already evident that integrative tools which are able to explore potential sustainable futures would, of necessity, have to incorporate models of the weather (climate scenaria), of surface and subsurface hydrology, crop growth, agronomic practices, and others. These models must reflect the issues of

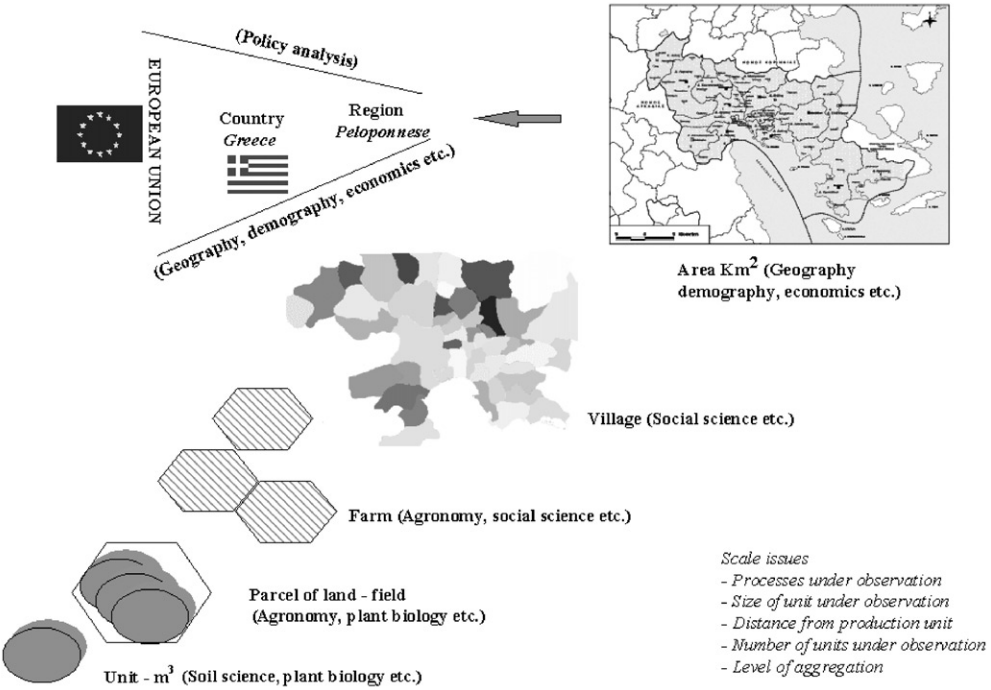


Figure 2. A representation of the disciplinary contributions to integrative research, and their relationship to issues of scale. This example is based upon the Argolid Valley, Greece.

scale, resolution and hierarchy for simulated futures to be interpretable within the appropriate socio-cultural and natural context. They must also make use of the conceptual models that emerge from social enquiry activities.

We have already introduced the role that can be played by social enquiry in the provision of a comprehensive, but low resolution, picture of natural phenomena (see also Lemon *et al.,* 1994). A more common role for social enquiry techniques is to improve our understanding of how individuals and groups perceive their landscape and the issues relating to it (Green & Lemon, 1996*b*). People behave according to their perception of a situation, and this behaviour is influenced by their knowledge, experiences, and the normative behaviour of those around them. The environment within which decisions are made and behaviours take place is subject to multiple interpretations, and what is considered important varies not only between individuals and groups, but their evaluation of an issue may well change through time.

It is not enough to dismiss or ignore different perceptions as 'irrational' or too problematic to take into account. This was important in the context of the Argolid where much of the technological intervention was based on scientific expertise and guidance. However, when the related decisions and behaviour did not conform to this technological model there was invariably confusion about what lay behind such 'irrational' behaviour and how it could be managed.

The scope of what is possible will also vary according to the available information and the cultural context within which that information is interpreted. This has been seen as central to the difference between decision space (what is perceived to be possible) and opportunity space (what is actually possible) (Lemon 1999*a*). An implicit criticism of much of the policy process, and indeed of science, has been that it has paid too little attention to the mis-match between the perception of issues and their 'objective' representation and 'rational' interpretation based upon an assumption of perfect information. One mechanism for mapping these qualitative opportunity and decision spaces into a simulation model, using 'decision trees' (see, for example, Blatsou, 1999; Oxley *et al.*, 2002).

Social enquiry can help us understand these different interpretations and provide us with an improved insight about the range of potential responses to different decision issues. These responses themselves can translate into representations of physical and natural phenomena. The socially determined propensity to take risks, combined with an awareness of cropping alternatives, might allow us to suggest whether crop change is likely (Winder *et al.,* 1998; Winder, 2000) and what the nature of that transformation could be. We can then look at the hydrological requirements associated with the change such as the crop requirements, the state of the aquifer, rainfall levels, etc. In projecting these relationships, we are starting to generate meaningful scenaria.

Modelling

A dynamic computer model may be 'essential for understanding reality, (but) should not be confused with reality itself' (Levins, 1966). It must reflect an appropriate balance between generality, realism and precision in its abstract representation of 'reality', thus maximising the clarity of observable changes significant for enhanced understanding of that 'reality'. Models confer an ability to learn from the future which can help us develop more sustainable land-use policies. Integrative dynamic simulation models can be used for the exploration of potential futures (through contextual interpretation of the dynamics emerging from carefully specified policy scenaria), but should never be used as a predictive tool, since it is not possible to capture all the uncertainties in human–environmental interactions within an abstract computer model. In a socio-cultural context, we have already highlighted the need to consider multiple possible futures, since the very sighting of a potentially sustainable future may provoke responses that deny its ever being reached.

The development of an 'Integrative Modelling Framework' (IMF) required the integration of multiple human and environmental processes, all of which operate within their own disparate (sometimes extreme) spatial and temporal scales. They describe changes across varying dimensions, and until now, have been represented by integral parts of initially separate and bounded models. The representations of the human and natural environments have necessarily been simplified, specifically to facilitate the linking of these disparate phenomena. This process of model development reflects the trade-offs between reality, generality and precision which will inevitably occur (Levins, 1966). The necessity for simplifications—whilst integrating disparate phenomena to create qualitative representations of change—has been highlighted by work elsewhere (Oxley, 2000; Oxley & Allen, 2000).

A number of key methodological questions have been raised in this pursuit of a transdisciplinary approach for exploring complex environmental issues. One aspect of that complexity is that it is subject to multiple interpretations, and what is considered important varies not only between individuals and groups, but their evaluation of an issue may well change through time. The scope of what is possible will also vary according to the available information and the cultural context within which that information is interpreted. However, in the same way that high-resolution data cannot usually be obtained to provide an overview of the physical environment, perceptual and ethnographic minutiae is seldom available to support such a picture of the cultural and socio-economic conditions. In both cases, specialist information is fundamental to understand the detail, but the dynamic nature of environmental issues, and the policies relating to them, can often mean that such insights arrive too late to support or inform adaptive responses.

Thus, we need a medium that can provide a simplified representation or model of a complex landscape. This representation must incorporate the different perspectives of those who are making decisions that impact upon that landscape. Also, by including local stakeholders in the process of articulating (specifying) and interpreting the model, an iterative process occurs whereby the model evolves in response to its context. Interpretation of the emergent dynamics can then begin to provide an enhanced understanding of the human and natural responses to a variety of policy instruments. Thus, where the same actors (A and A^1 in Fig. 3) are interpreting the modelled output their view of the world may be altered. It is this reflection that can form the basis for policy-relevant exploration where different futures, and pasts, are explored and potential responses considered. This makes the involvement of local stakeholders in the integrative research process essential.

This need to include local actors, or 'stakeholders', in the description, specification and interpretation of models has been demonstrated previously (Lemon *et al.*, 1996), and the inherent complexity of the socio-cultural and natural environments has been highlighted by Lemon *et al.* (1999). The value of an interactive approach to model development and an improved definition of the policy spaces driving the model is clear. It is represented in Fig. 4 by the feedback between the model output (interpretation) and its inputs (scenaria), thus providing the cultural context for exploring different policy options.

This schematic representation of the IMF (Oxley *et al.,* 1999, 2002) highlights the role of the user and thereby the ability to use the model with culturally and geographically diffuse stakeholders. Starting with the physical boundaries of the study area, additional models are overlaid and their spatial and temporal interactions and interdependencies defined. Unlike classical GIS techniques this is not purely a mapping of layers of data in geolocated space. It is instead the integration of multiple, inter-related and dynamic processes within the landscape, defined within models that operate at multiple resolutions and with different, sometimes dynamic, timesteps

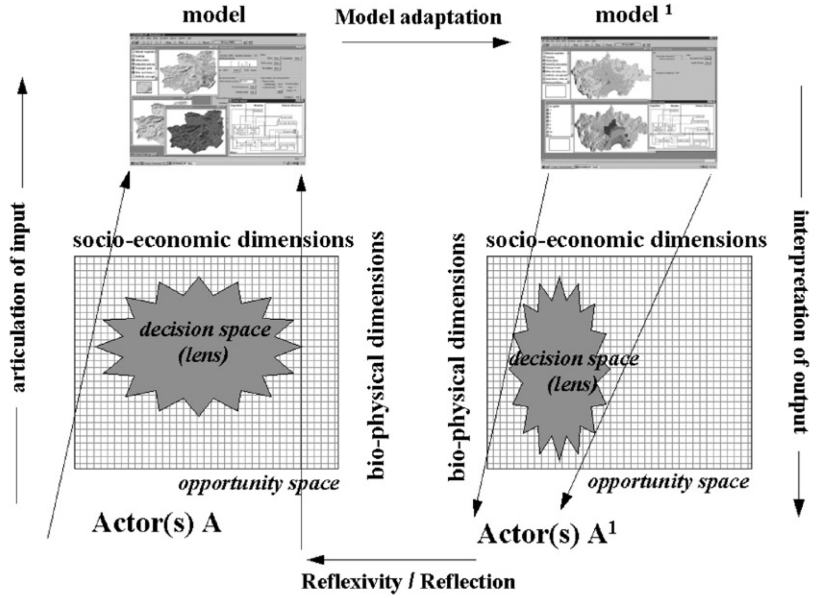


Figure 3. Different actors will perceive the world through different 'lenses' and their perceptions may be altered through model interpretation, contributing to the iterative process of model development within any given context (adapted from Lemon, 1999*a*, *b*).

(see, for example, Mulligan & Reaney, 2000; Reaney & Mulligan, 1999). The Archaeomedes IMF models relate to:

(i) aquifer hydrology on a regular spatial grid (Robinson, 1999);
(ii) the surface river hydrology with its topographically defined irregular spatial boundaries (Billen *et al.,* 1990; Allen *et al.*, 1996);
(iii) the soil and slope hydrology defined using a regular grid within the catchments (Oxley *et al* 1998); and
(iv) the human dynamics (in this instance, the local farmers) and demographic influences using both regular spatial representations and predefined administrative regions (Winder *et al.*, 1998; Winder, 2000).

In order to adapt and enhance this IMF to develop a 'state-of-the-art' *decision support system* (DSS) (Engelen *et al.*, 2000), alternative models of weather and slope hydrology (Mulligan, 1995, 1996*a*, *b*, 1998; Burke *et al.*, 1998; Reaney & Mulligan, 1999) and aquifer dynamics (Giannoulopoulos, 2000) were integrated, together with additional models of natural vegetation (Mazzoleni *et al.*, 1998; Legg *et al.*, 1998) and land-use dynamics (Engelen *et al.*, 1995, 1997; White & Engelen, 1993*a*, *b*, 1997; White *et al.*, 1997).

Both the Archaeomedes IMF and Modulus DSS retain most of the characteristics of the individual models, and, by using a common central database and a high-level driver—which coordinates the disparate temporal and spatial scales using state-of-the-art 'component' technologies (van der Meulen *et al.*, 2000)—it is possible to present a more holistic framework whereby the interactions between the sub-models highlight many of the critical dynamics of change. Previously, these could only be dealt with through user definition of extraneous influences. Details of the spatial and temporal interactions and mappings, and the data flows between each model are documented elsewhere by Oxley *et al.* (2000, pp. 316–327).

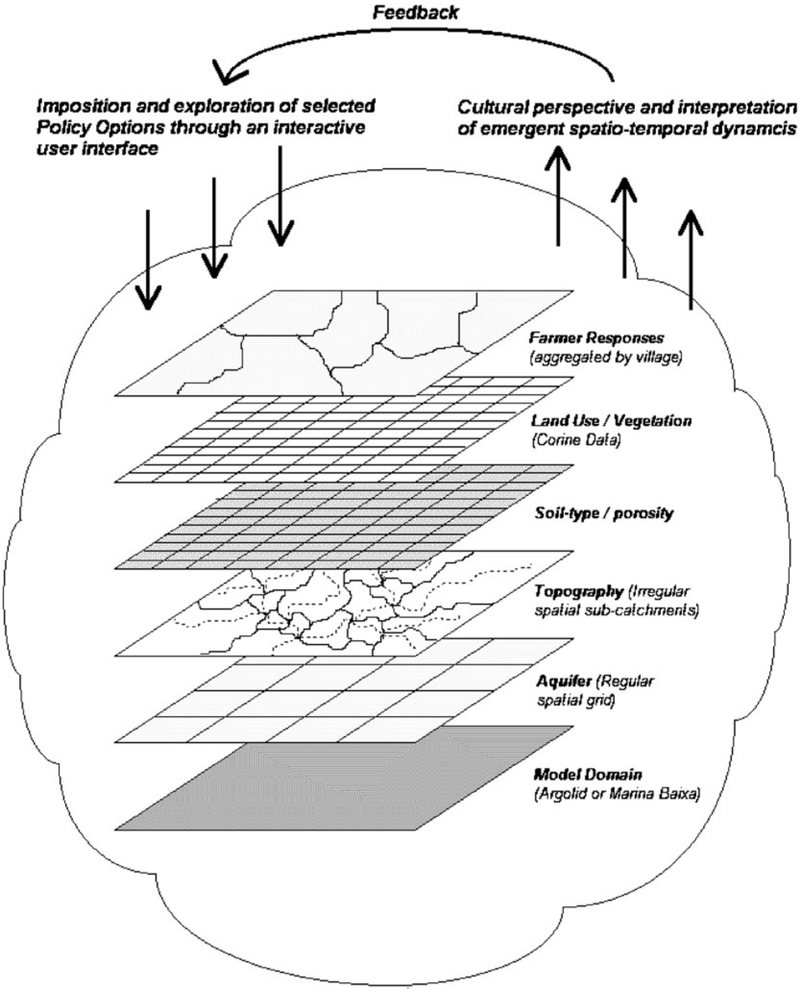


Figure 4. A conceptual representation of the multiple interacting models and feedback involved in evaluating policy options and interpreting the emergent spatio-temporal dynamics.

This suite of models are driven by selected policy interventions likely to promote change in human systems, with consequential effects upon the natural environment from which the spatio-temporal dynamics of the system will emerge. Interpretations of these emergent dynamics, accounting for the socio-cultural perspectives evident in the region, can provide the necessary ‘grounded’ information for redefining policy options. These in turn form the basis for further simulations.

The individual models that are integrated within this framework each operate within and across disparate spatial and temporal scales. They vary temporally from the hourly (for slope hydrology, surface runoff, etc.) to the annual (crop choice decision making), and spatially from 100 m through 1 km (aquifer model) to the spatial dimensions of entire sub-catchments in the region. The individual models retain their own timesteps, and these and the spatial mappings between different model domains are coordinated by the high-level driver.

More complex than the spatial disparities between the individual models are the temporalities involved, with significant disparities between the timing of events and their consequent effects. As shown in Fig. 5, the temporality of events within individual models varies from the hourly to the annual, mirroring the short-term, localized effects and the long-term, regional effects of change. However, we also find that the temporality of effects varies from the daily to decades when observing the effects of annual crop choice dynamics emerging from the simulated farmers in the system. These variations in the temporal effects of change were reflected by simulation output which has been documented elsewhere (Oxley *et al.*, 1999), and verified using the Modulus DSS (Engelen *et al.*, 2000).

Some of these temporalities are evident in the simulation outputs presented below, in relation to irrigation practices and technologies. The *daily* events resulting from the type of irrigation technology used (drip or flood) imposes demands for water, the effects of which only become apparent in reservoir levels in the Marina Baixa, Spain, over a period of *months* (see Fig. 6). In the case of the Argolid, they are only significantly noticeable in the aquifer after a number of *years* (see Figs. 7 and 8).

Decision support tools

The primary objective of the Modulus project (Engelen *et al.*, 2000) was to adapt the IMF—a suite of *research models* developed for the Archaeomedes (II) project (Oxley *et al.,* 1999, 2002)—so that, together with other selected models emerging from the Medalus, ModMED and Efeda projects of the European Union, it could be integrated with the Geonamica® software to develop an Integrated Spatial Decision Support System (DSS)—driven by a suite of *policy models*—for use by local policy makers. The outcome of this research has been to

(i) develop a suite of *integrated policy models* addressing climate, (sub-)surface hydrology, natural vegetation, agronomic activities, socio-economic influences and land-use dynamics;

(ii) provide a user-friendly *dialogic interface* which allows policy makers to define appropriate scenaria for examining a variety of policy options. An example of this interface, showing the weather model dialogue and Modulus DSS system diagram is presented in Fig. 9;

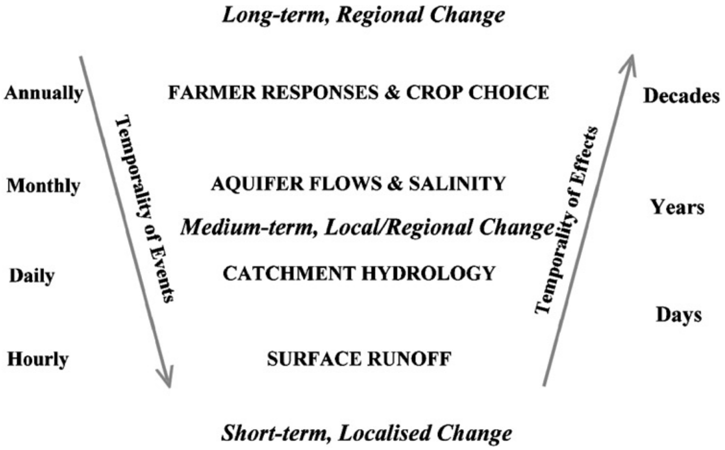


Figure 5. Identification of the temporalities involved within both the Archaeomedes IMF and the Modulus DSS, highlighting the temporalities of events, the temporalities of the effects of change and the relationship with localized or regional change.

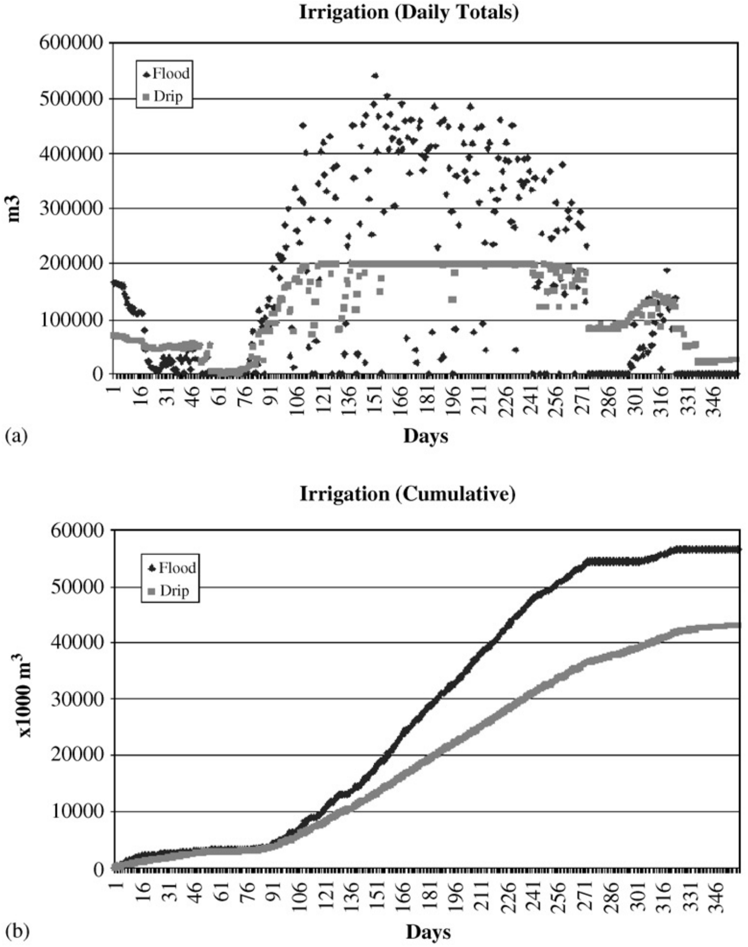


Figure 6. Time-series outputs showing the effects of drip and flood irrigation on (a) a daily basis, and (b) cumulatively over 1 year.

(iii) simulate *policy scenaria* in order to verify the potential utility of the decision support tool in selected contexts that are relevant to the case study areas;
(iv) involve end-users in *workshops* in both case study regions, to review the potential for such decision support tools in exploring sustainable futures.

Each of these outcomes are critical to the use of integrative modelling for the exploration of potential pathways towards more sustainable land-use decisions and management. The models themselves provide the simulation ‘engine’, the dialogic interface is necessary to assist the end-users in scenario generation and interpretation, and the ability to simulate policy scenaria which are relevant to the socio-natural context of the particular environment is crucial. The final point reflects the importance of local stakeholders being involved in both the model development and use; the people who know the characteristics of the region, will respond in complex ways to different policy instruments, and who are thus central to developing sustainable pathways.

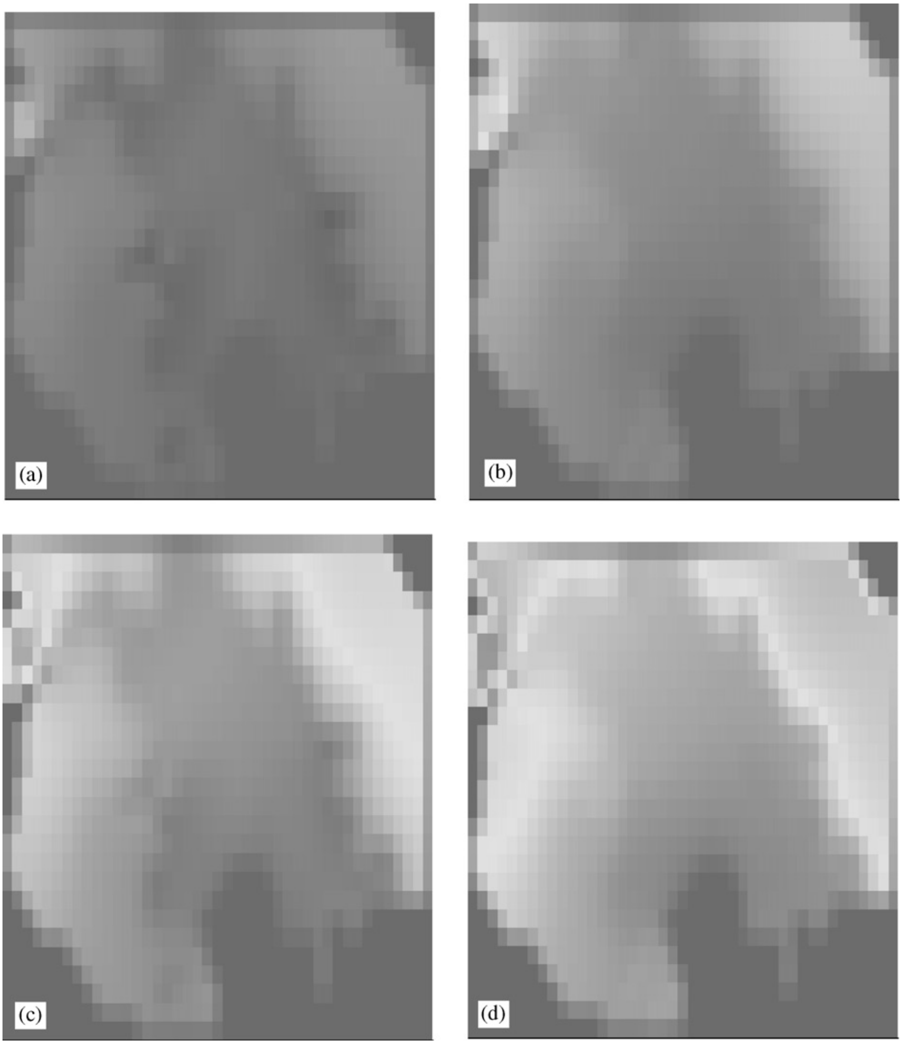


Figure 7. Changing water height in the aquifer at (a) 30 months, (b) 60 months, (c) 90 months, and (d) 120 months; lighter areas represent relatively lower water levels.

Thus, any exploration of more sustainable, or perhaps more importantly the identification of non-sustainable, futures will require the simulation and interpretation of carefully defined policy scenaria. The range of scenaria which the Modulus DSS can potentially address include:

- Water management, aquifer recharge, water stress, etc
- Economic policy, crop choice and subsidy.
- Long-term climate change and desertification.
- Urban development and tourism.
- Planning and land suitability mapping.

Details of the models used in the Modulus DSS, together with discussions of the case-study areas and the complex problems encountered whilst integrating socio-natural models, are comprehensively documented by Engelen *et al.* (2000), with an

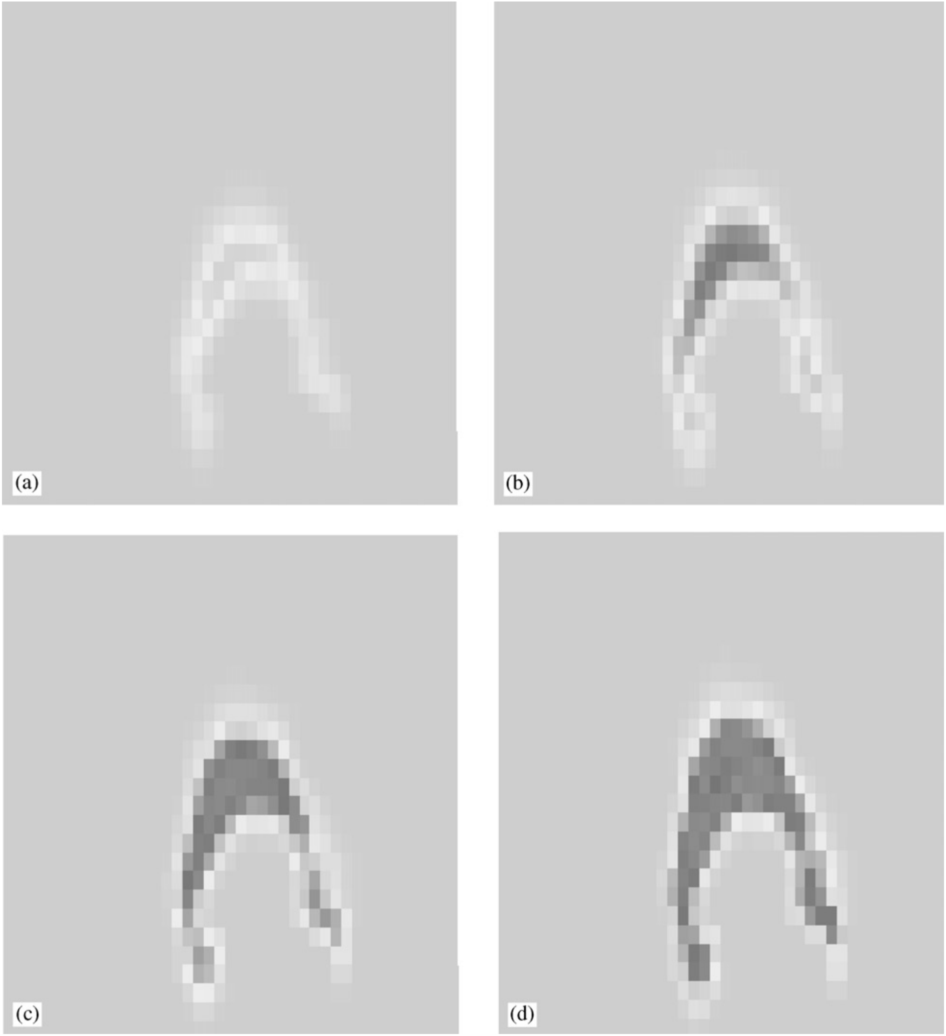
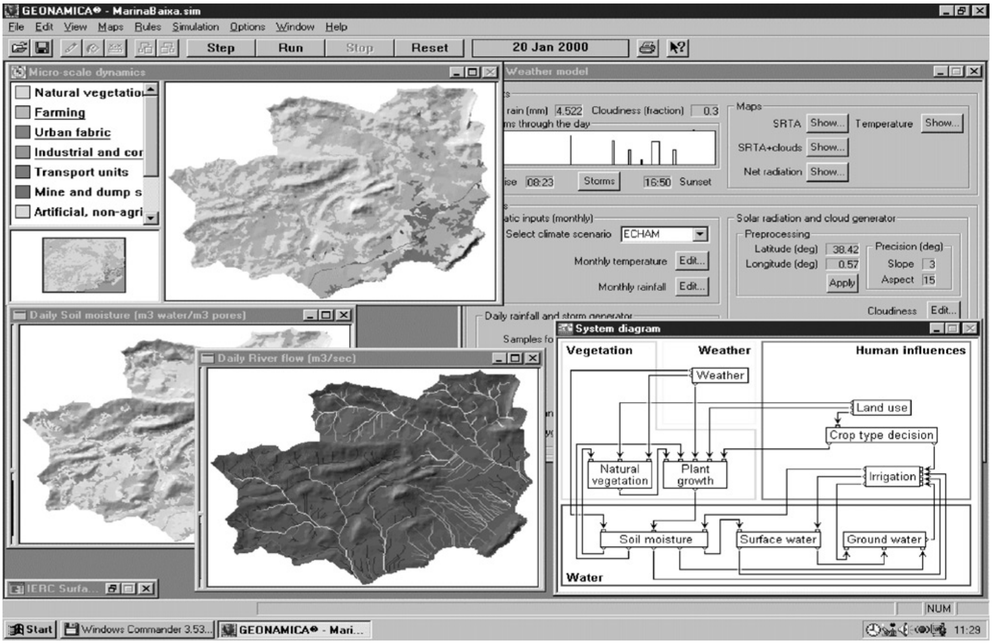


Figure 8. Changing water salinity in the aquifer at (a) 30 months, (b) 60 months, (c) 90 months, and (d) 120 months; darker areas represent relatively increased salinity.

evaluation of the system provided by Muetzelfeldt (2000). In this paper, we will now present two simulations which show how the emergent socio-natural dynamics are linked to the actions and responses of local farmers, thus also highlighting the need to involve local stakeholders at all stages of integrative research activities.

Irrigation technology in the Marina Baixa

In the Marina Baixa, there are severe shortages of water for both agricultural purposes and human consumption. This provokes potential competition for water between the local farmers and the Benidorm hoteliers who service the tourist industry (Mata, 1999; Mata & Lemon, 1998). From the perspective of the farmers, the balance of available water can be influenced by a number of factors: the crop type and the irrigation technology used; the predispositions of farmers to certain



20 Jan 2000

rain (mm) 4.522 Cloudiness (fraction) 0.3

rise 08:23 16:50 Sunset

Select climate scenario ECHAM

Latitude (deg) 38.42

Longitude (deg) 0.57

Slope 3

Aspect 15

Figure 9. An example of the Modulus DSS user-interface, showing the application to the Marina Baixa (Spain). The system diagram, the climate model user dialogue window, and selected dynamic model outputs (river flows, soil moisture, etc.) are shown.

crops—particularly medlar (nisperos) in this region; the soil moisture threshold at which they begin irrigation; and the economic and technical ability to utilize new technologies. The range of influences and the importance attached to them can only be determined through carefully directed social enquiry (see, for example, Lemon, 1999*b*). This information guides the development of models of farmer behaviour, and the emergent effects suggested by integrated human and natural models can only be interpreted within context by local farmers, farming cooperatives, etc.

The example presented here involves the use of different irrigation technologies, looking at a comparison of drip and flood irrigation practices. Of course, both technologies are utilized in the Marina Baixa, but we simulate the extremes of using one technology or the other to emphasize their differing impacts upon water resources. The Modulus DSS is able to generate and present both spatial and time-series data, and in Fig. 10 we can see a spatial snapshot of simulated irrigation in late June. The spatial difference between the two technologies is evident, with more continuous, but lower, rates of irrigation relating to drip technology, and more spatially fragmented (but higher) rates with flood irrigation. These characteristics are also highlighted in Fig. 6(a), which shows time-series outputs and highlights the intermittent nature of flood irrigation and the significant differences in the amount of water required on a given day. Fig. 6(b) shows the cumulative effects upon the total water requirements over a year; in this simulation it suggests that drip irrigation across the catchment could potentially save 15 million m^3 of water annually.

Most of this irrigation water is abstracted from the Guadalest reservoir, which itself is augmented by two springs: Beniarda, which is upstream, and Algar, from which water must be pumped uphill to recharge the reservoir. Fig. 11(a) shows the water levels, augmentation and demand from Guadalest as defined by empirical data, whereas Fig. 11(b) highlights the necessity of Algar spring water for augmentation in

Figure 10. Simulated irrigation rates for 21 June 2000 in the Marina Baixa using (a) drip, and (b) flood irrigation technologies.

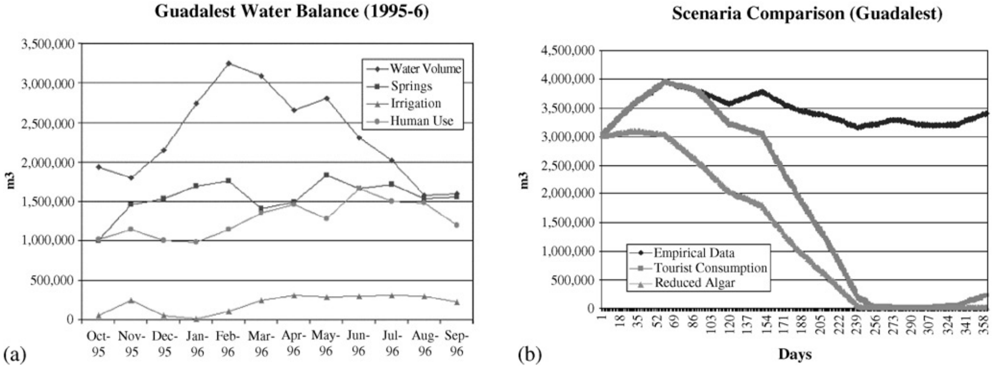


Figure 11. (a) Empirical data relating to the Guadalest water volume, spring flow and human demand for water, and (b) the effects of reduced augmentation from Algar springs, and increased abstraction to service summer tourism, on the water levels in the Guadalest reservoir.

order to match the seasonal demand for water from tourist development in Benidorm and the surrounding areas.

This simple example clearly emphasizes the importance of thinking in an integrative and systemic fashion, and of involving local stakeholders in the entire research process so that appropriate scenaria are simulated and the emergent dynamics can be interpreted within the local socio-natural and cultural context. Interpretation requires that both scientists, who understand the technology, and local stakeholders are involved in the process.

Subsidies on oranges in the Argolid Valley

The example we present in the Argolid Valley, Greece, relates to the effects of crop choice decisions as opposed to the use of different technologies. Again, carefully directed social enquiry activities were necessary to elicit the characteristic responses of farmers in the region to water availability and quality, EU subsidies etc.

(Blatsou, 1996; Lemon *et al.*, 1998; Seaton *et al.*, 1998; Lemon 1999*a*). This elicited understanding was used to develop a number of models of farmer crop choice decisions using econometric (Seaton & Black, 1999), master-equation (Winder *et al.*, 1998), and 'decision tree' techniques (Blatsou, 1999; Oxley *et al.*, 2002).

The outputs presented in Figs 8, 12 and 13 highlight the linkages between farmers' responses to both natural conditions and policy influences, and their longer term impacts upon land cover and ground-water quality. Figure 12 shows the crop distribution at the beginning and end of a 50-year simulation based upon the master-equation model, considering the effects of subsidizing orange production. Where no

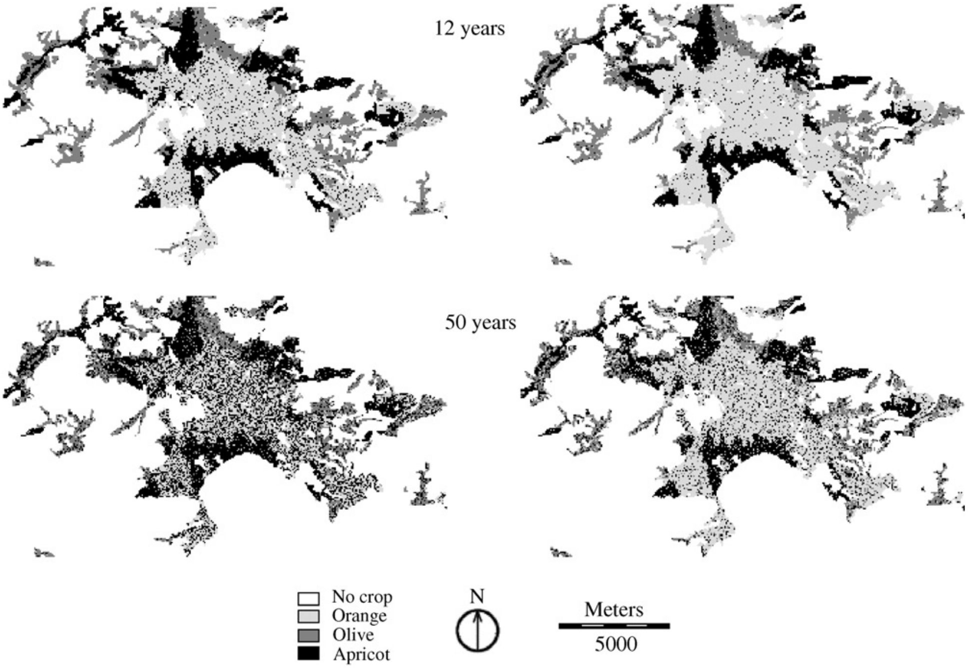


Figure 12. The changing crop distributions after 12 and 50 years of simulations with (a) no subsidies, and (b) a subsidy on orange production.

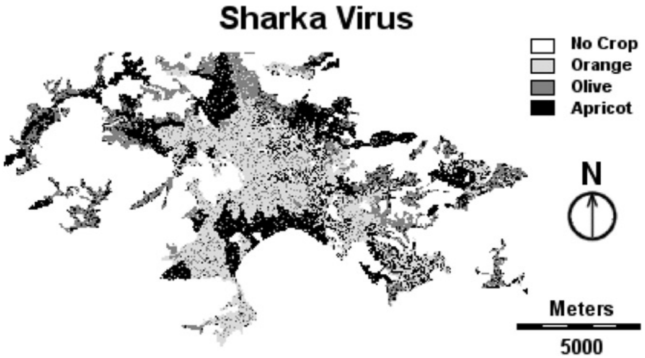


Figure 13. Crop distributions after 50 years, taking into account farmers predispositions concerning the Sharka Virus.

subsidies are available the area covered by apricots increases dramatically since the crop demands a higher price in the open market than oranges. In Fig. 13 we can observe a different dynamic when using the decision-tree-based model. The Skarka Virus decimated apricot production in the Argolid between 1987 and 1993 (Lemon & Blatsou 1999*a*, p. 87; Lemon, 1999*a*, p. 38) and in the villages where the farmers retain a memory of Sharka, they are disinclined to replant, even if it is likely to be profitable; Fig. 13 highlights this dynamic.

These changes in crop distributions also highlight the disparate temporalities discussed above (see Fig. 5). In the model crop decisions can be made on an annual basis, however, the qualitative spatial effect on land-cover, although becoming visible after 12 years, only become significant over five decades. The effect of these crop distributions upon the aquifer—through pumping for irrigation—is also evident in the simulation outputs. In the scenaria shown, both apricots and oranges are irrigated crops and influence the demand for irrigation water. The effects of over-abstraction over a 10-year period, leading potentially to both boreholes drying up and aquifer salination can be seen qualitatively in Figs 7 and 8 (Lemon, *et al.*, 1994; Seaton *et al.*, 1998, Lemon, 1999 *a*; Poulovassilis & Giannoulopoulos, 1999).

These dynamics have been simulated using Robinson's (1999) model, as reported by Oxley *et al.* (2002). Figure 7 shows the drop in water levels in the aquifer at 30-month intervals; the lighter the image, the lower the water level in the aquifer. The effect of this lowering of the aquifer is seawater intrusion and salination. In Fig. 8 the darker areas of the plume spreading from the coast reflect higher salt concentrations. If the simulation were to be continued, we may expect salt-intolerant crops (e.g. oranges) to be replaced by salt-tolerant crops (artichokes, nuts, etc.). Certain replacement crops might not be taken up by some farmers because they had no history in the area (nuts); they involved too much labour (vegetables) or they would take too long to realize an income (olives). There are multiple 'rationalities' that we need to understand. Alternatively, a change in rainfall patterns (such as occurred between 1994 and 1996 when rainfall increased from 500 mm to 900 mm per annum, Lemon & Blatsou, 1999*b*) may help to recharge the aquifer, thus reducing salinity and retaining the capacity to grow oranges. These provide examples of how decision-support tools can be useful for iterative exploration of potential futures. They also warn against the inappropriate use of such models for predictive purposes.

Conclusions

This paper has argued for an *Integrative Modelling Framework* that complements rather than competes with established disciplinary-based approaches. The environment is essentially a complex mix of human, physical and natural systems whose interactions create unique local landscapes that change through time. The fundamental question of sustainable development is to improve our ability to respond to those changes in such a way that future possibilities are not removed. The message of this paper has been that we need to learn from, rather than predict, the future. While this may appear a vague and unsubstantiated notion, we argue that because the future cannot be known—and if it were possible we would alter our behaviour in response to that knowledge—we need to generate potential futures as a way of expanding our knowledge base. It is this exploration of *potential* futures, or scenaria, combined with our understanding of existing conditions (particularly the perceptual differences of human actors) that can provide us with the necessary insights into the range of possible policy responses and interventions.

We have presented an integrative modelling framework that pulls together data of variable resolution about anthropogenic, natural and physical phenomena operating at different scales. Inevitably, this approach requires compromise in what is perceived as acceptable data. A number of points need to be reiterated in response to this:

- Firstly, because of the dynamic nature of environmental systems the world has invariably moved on before we have data of sufficient resolution to be useful. We need to be able to explore the future in an ongoing manner and this needs to be underpinned by established science. This process of exploration should also provide some guidance as to where that science could be targeted.
- Secondly, policy-relevant modelling is ultimately for exploration by users (i.e. policy makers and administrators at different levels) and not scientists. While we should be vigilant about such models being taken too literally, we should also recognize that the models are for generating scenaria by users who are not necessarily conversant with the data and the methodology that underpins the model itself.
- Thirdly, while models, like policy, need to be grounded in, and relevant to unique locations, they must be transferable and not restricted to those locations. While we have argued that we must start with the local in all its complexity, it is the ability to develop an accessible, transferable and integrative framework that provides us with our greatest challenge.
- Finally, the starting point for understanding environmental change must be to have an improved knowledge of what issues are salient to local stakeholders and to be informed about how these perceptions are likely to affect their decisions and behaviour, towards and in response to, the environment.

Throughout this process we have shown a need to think systemically—operating across disciplinary boundaries and integrating phenomena which operate at disparate spatial and temporal scales; involve both scientists and local stakeholders in the research process—to elicit understanding of the human processes and contextually interpret simulation outputs; and to design simulation scenaria which relate to policy mechanisms affecting the socio-natural environment. Integrative research and modelling is an iterative process which requires continual reassessment of both conceptual models and simulation models (see Fig. 3).

Through the integrative research discussed in this paper, resulting in the development of the Modulus Decision Support System described above, the following has been achieved:

- The involvement of local stakeholders in the entire research process, from the initial social enquiry activities (e.g. local farmers), through model design (local scientists, end-users, etc.), to the interpretation of simulation outputs (farming cooperatives, decision makers).
- The integration of human and natural dynamics, operating upon different spatial and temporal scales, in a state-of-the-art simulation environment accessible to both scientific and policy-oriented audiences.
- The transformation of *research* models developed in different disciplinary contexts into *policy* models, without undermining the scientific content of individual models (see, for example, Mulligan, 2000, p. 141).
- Through stakeholder involvement in workshops, have shown how integrated models can be used as learning tools as opposed to predictive devices, potentially empowering users through the definition and interpretation of scenaria and increasing understanding of their local socio-natural environment; to quote one key workshop participant *'Finally, we stop being*

> *the aboriginals that are studied by civilised people, and from now on we will start collaborating with them at the same level*' (Filippucci *et al.*, 2000, p. 94).

Finally, integrative research invariably gives rise to a variety of problems, many of which were encountered during the research described above. The problems encountered are discussed in more detail in the various literature cited in this paper, but some of the key lessons learnt include:

- The difficulty of representing human dynamics, and importance of stakeholder involvement in the entire research process. Stakeholders help in the elicitation and interpretation activities, with the human dynamics being represented through 'decision trees' and 'master-equation'-based models.
- Iterative development and usage of simulation models is central to integrative research, so that potential futures can be explored, and the increased understanding used to drive any adaptation required of the representations used within the models. Again, interpretation of these potential futures requires both scientific rigour and the contextual knowledge retained by local stakeholders.
- The conversion of research models to policy models inevitably results in certain compromises. Models often require modification, and sometimes must be re-written, creating conflict between scientists and modellers who wish, quite correctly, to maintain the integrity of the science. This always requires a careful balance between realism, genericity and accuracy, as discussed by Levins (1966).
- The complexity of integrating multiple spatial and temporal scales should not be underestimated, particularly when models originate from diverse sources and disciplines, often operate within different conceptual frameworks, and use conflicting software engineering techniques, as was the encountered during the development of the Modulus Decision Support System (see van der Meulen, 2000, p. 269).

We wish to thank our partners in the Archaeomedes and Modulus projects for their contributions to the work upon which this paper is based We would also like to acknowledge Dr Juval Portugali of Tel Aviv University for the phrase 'learning from the future' which we feel is particularly apposite to the message we are attempting to convey.

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