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An integrated dynamic model for economic development and natural environment: An application to the Greek Sporades Islands*

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This paper presents a modelling study on regional sustainable development. First, the use of formal modelling for studying the multi-level relationship between economic, environmental and development processes is discussed. Such a relationship is analyzed for an island region in Greece. A potential conflict exists here between environmental conservation, local interests and rapid growth in tourism. A dynamic model is used to depict the development of the economies of three main islands and their interactions with the terrestrial and marine environment. The presentation of the case study model is followed by a discussion of scenarios, indicators and simulation results.

Keywords: System dynamics, tourism development, recreation.

Subject classification: JEL C44, C52, Q26.

1. Introduction

The end of the eighties has shown an increasing number of studies devoted to the conflict between development and environmental conservation. A benchmark for many of these studies is the publication of the well-known (“Brundtland”) report “Our Common Future” by the World Commission on Environment and Development [22]. The particular aims of the various studies, however, differ considerably. Most of them seem to rely on informal analyses.

In the present paper, we investigate the conflict between *economic development* and *environmental conservation* using formal models. In particular, we apply a model to an island region in Greece, the Northern Sporades. A *dynamic model* has been set up which describes the development of the economies of three main islands, and interactions with the terrestrial and marine environment. The problem to be solved can be regarded as a search for regional environmentally sustainable development,

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i.e. a non-decreasing regional welfare level in the long run. Several problems are important in the regional setting. First, by exporting pollution, or importing natural resource materials, regions may develop quickly but at the cost of extra-regional environments. Second, extra-regional support of development and growth may push a regional economy beyond certain regional environmental limits, at the risk of irreversible destruction of regional ecosystems. Finally, this risk may become more serious when certain factors outside the region strongly push its internal growth. In the case study especially the latter two problems are relevant, since tourism is a rapidly growing activity in the region (for details, see Giaoutzi and Nijkamp [10]).

The introduction of a conceptual framework in section 2 allows us to emphasize the main difference between the present application and other related studies. In section 3, we discuss the modelling of economy–environment interactions in the context of long-term development analysis. A description of the case study area and problem is given in section 4. Section 5 explains the structure of the case study model. Scenarios, indicators and simulation results obtained by means of the model are discussed in section 6. Conclusions are presented in a final section.

2. A framework for the analysis of economic development and natural environment

At the basis of this study is the search for *sustainable long-term environment–economy relationships*. Here we are concerned with the choice of an analytical framework for modelling economic development in relation to relevant characteristics. It may be based on a scheme such as shown in figure 1. Endogenous long-term

Figure 1. A framework for economic development and long-term environmental conservation.

growth and development are important here, since we are interested in a sustainable state that can be generated by forces from within the regional economic system. A special type of development within this framework is the investigation of environmentally

sustainable economic development (see WCED [22], Archibugi and Nijkamp [1], and Van den Bergh [4]). We will regard *sustainable development* as a long-term process of economic activities, technological progress, population growth, material flows and economic-environmental interaction that satisfies certain conditions, which may be referred to as sustainable development conditions. These conditions can be based on a combination of *ecological* and *ethical* information. The first type of information refers to our understanding of ecosystem processes and environmental effects of economic activities. The second type of information derives from value systems about the role of man towards environmental integrity, and the role of present towards future generations (see Van den Bergh [3, chapter 2]). For long-term development, it is relevant to link the difference between realized values of environmental-economic interaction levels and sustainable development conditions to economic activities, so that adjustment to a more desired sustainable situation can take place. This type of link may occur by way of a dynamic feedback process, starting with an evaluation of the actual versus the desired situation, followed by necessary corrective or adjustment actions related to, for instance, investment. Related to this conception of feedback processes is an interesting “ecological view of economic development” provided by Wilkinson [23]; see also Common [8]. It regards economic development as a necessary process of adaptive responses to an “ecological disequilibrium”, caused by exogenous phenomena (e.g. disturbing isolated socio-economic systems, such as tribes). Related views on a strong interaction between natural and economic long-term processes are expressed as (co)evolutionary views (see Boulding [6], and Norgaard [18]).

The advantage of our approach is that it circumnavigates the rigid character of fixed deterministic conditions in the long run. Instead, conditions are more or less used in an approximate sense, by way of an adjustment process linked to feedback of information about differences between sustainable development plans and development outcomes.

In effect, development processes are in the framework perceived in terms of *indirect* economy–environment processes. In addition, one has to devote attention to more short run processes that occur at the crossroads of economy and environment. We may refer to these as *direct* economic–ecological interactions which include straightforward relationships between production, consumption and welfare on the one hand, and natural systems on the other hand. Examples are:

- positive and negative effects of production on the environment, caused by environmental protection, or polluting, extracting and disturbing activities;
- negative effects of consumer behaviour on environmental quality, e.g. recreation;
- positive influences of the environment on production, e.g. in terms of soil conditions for agriculture, or marine quality for fishery;
- positive influences of environmental characteristics on consumption, e.g. recreation;

- material flows from the extraction of renewable and non-renewable resources; and,
- material flows from waste generation to the environment.

A full treatment by way of formal modelling will have to reckon with both the direct and indirect economy–environment interactions.

3. Models for economy, environment and development

In addition to direct economy–environment relationships, this study is concerned with two additional dimensions, namely that of long-term change (development and growth) and the regional scale. With regard to the latter, cross-boundary flows of materials and extra-regional influences of internal development deserve specific attention. In a general long run regional framework, one may distinguish between the following types of relationships between the elements of development, economy and natural environment: (i) *direct impacts* of the economy on the environment, through extractive, insertive (e.g. pollution) and disturbing activities (e.g. land use and transportation); (ii) *direct positive and negative impacts* of the environment on the economy, through the provision of resources and assimilative capacity, necessary conditions for production (e.g. agriculture) and consumption (e.g. recreation), and damages occurring from ambient pollution and degradation of natural systems; (iii) *impacts of development on the economy*, through capital accumulation, sectoral changes, demographic changes, technical change, and the above-mentioned external determinants (e.g. tourism); and (iv) *impacts of natural, environmental circumstances and changes therein* on decisions and actions that form part of development processes. Examples of environmental causes are scarcity of natural resource, a decrease of environmental quality, an overshooting of carrying capacity limits (by population, tourism, or economic growth). This may give rise to migration, introduction of new technology, and public policy. The impact sequences that go from (iii) to (i) and from (iv) to (iii) can be regarded as *indirect impacts* from development to environment, and from environment to economy, respectively. A recognition of these various relationships is required because we are interested in long-term relationships.

In particular, the *integration* of economics and ecology is important for a study of the relationships mentioned above. Here the use of formal models is necessary, in which processes of both fields are described in relation to one another (see Van den Bergh and Nijkamp [4]). This may be a fruitful direction for three reasons. First, there is some similarity between the sub-disciplines mainly dealing with an *aggregated* level of analysis, namely regional and macro economics and synecology (see van der Ploeg [20]). Second, both fields have a *tradition* in theoretical and applied modelling. Third, *methodological* differences are circumvented to a certain extent in this way. The specific accumulated disciplinary knowledge is used to establish the structure of the model, select the elements and specify their relationships (see Braat and van

Lierop [7]). Furthermore, one may use a *systems approach* that focuses on elements, their relationships, causality, and feedback mechanisms. Looking at both the economy and the environment in terms of systems yields a “common denominator” and allows one to provide for interactions in a systems theoretic framework. Thereby, one may imagine the economic system within the environmental system, or perceive them as two coupled subsystems, or instead regard them as one entire system. One can observe these systems on various levels, taking into consideration energy, matter and information. Process descriptions may involve biological, chemical, physical, monetary, behavioural, institutional and organizational relationships (see Bennett and Chorley [2]).

Most models that focus on environmental economic problems have not addressed issues of development in terms of adaptation and multi-sectoral growth (see Braat and van Lierop [7]). Some exceptions are purely theoretical (e.g. energy models by Odum [19]), consider management practices rather than overall development (e.g. Holling [11], Lonergan [15]), or take a very aggregate perspective such as the well-known global models (Meadows et al. [16,17]). Finally, operational modelling on a regional scale has led to various types of systems models, integrating economics with environmental modules, partly based on materials balance conditions (see Kneese and Bower [13], Lakshmanan and Nijkamp [14], James [12], and Van den Bergh [5a]).

“*Integration*” in the present study encompasses the following four levels (see Van den Bergh [3]): (i) *material flows* between economy and natural environment based on materials balance conditions; (ii) *effects of human systems* (economy and population) on environmental quality through immaterial or less-tangible categories of impacts such as land use, noise and soil exploitation; (iii) *effects of environmental conditions* on economic production, consumption and health, including for instance negative pollution effects; and (iv) *production functions* with a mix of economic and natural factors of production.

4. Region and problem description

The Northern Sporades are a complex of islands located in the Aegean Sea close to central Greece (see Giaoutzi and Nijkamp [10]). They constitute an area where socio-economic objectives conflict with environmental conservation objectives. This area embraces the inhabited islands Skiathos, Skopelos and Allonisos, and some uninhabited islands. For the purpose of the present study, a nearby, low-developed area on the mainland, Pillion, has been included in the analysis as well, because of spillover effects that may result from quick economic development induced by tourism on the islands. The population levels in 1985 of Skiathos, Skopelos, Allonisos and Pillion are 5064, 4226, 1621 and 600, respectively. Table 1 shows *land cover data* for the three main islands.

There exists a rich vegetation on the islands, including pine forests and different types of Mediterranean scrubland (indicated by the French names *maquis* and *garrigue*). Both flora and fauna include many interesting, and some unique, species. There is

Table 1

Land cover data for the three main islands (1985); beaches not included
(source: Frantzi and Despotakis [9]).

× ha	Skiathos	Skopelos	Allonisos
Natural vegetation	1740	4580	72060
Pasture	1580	2630	5660
Cultivation	1408	2048	1920
Urban infrastructure	340	390	2250
Total area	5068	9648	81890

a natural process of exchange between different types of vegetation like forest and scrubland. Maquis is naturally transformed into forest vegetation. Occasionally, the rate at which the process in the other direction occurs – from forest vegetation to maquis, and from maquis to garrigue – is increased by fires. These are more likely when many tourists are staying in the natural areas. Bare land constitutes an important part of the natural area, because of natural conditions such as high elevation levels and/or dry or rocky soils. The land use patterns of agriculture (grazing of goats and cultivation for crop and fruit production), urban areas and road development dominate the changes in available land for natural vegetation. Expansion of agricultural land has mainly transformed areas with low-growing scrubs or bare land. Urban land is expanding around the villages, usually into former cultivated or agricultural areas. Degradation of the natural vegetation as a result of agricultural and urban expansion, tourism and natural processes induces soil erosion by wind and water. This makes natural recovery of transformed areas rather unlikely. Disturbances of quiet by tourists is another element that may harm especially the fauna.

The marine environment is rich in species, such as corals, different types of fish, dolphins and the Mediterranean Monk seal (*Monachus monachus*). This latter species is very valuable from a conservation point of view: it is unique, rare and highly valued by tourists (laymen) and biologists (experts).¹⁾ In addition, the Monk seal is a critical part of the marine ecosystem, in which it is situated at the top of the food chain. The existence of this species is, however, threatened by sea water

¹⁾ The Monk seal was once found along all shores of the Mediterranean Sea (and a few other places around the world). The World Wide Fund for Nature (WWF) ranks it among the ten most endangered species in the world, with only 400 to 600 individual animals presently surviving. The greatest number is found along Greek and Turkish coasts, and among the Aegean Islands. They are the largest of seals, weigh about 250 kg, measure 2.5 to 3 meters in length, and have an average life span of 10 years. They prefer coastal areas. The main threats to their existence are habitat destruction, marine pollution, competition with fishery for food, and hunting (see, e.g. The World Bank/The European Investment Bank [24]).

pollution, fishing and tourism in the area. The number of seals has gone down and stabilized in recent years to a present level of approximately 40. Below, the attention is focused on three types of fish and a lobster species, located at one and the same level in the food chain. The threefold classification of fish is related to their economic value: the first class includes fish like red mullet; the second class includes swordfish and melanuria; and the third class includes gopes and tuna. They are distinguished for economic reasons. The first type of fish and lobster are the most expensive. The catch of fish types two and three, however, is much higher, and in effect all of them may be regarded as equally important for realizing economic objectives in the fishery sector.

A marine park was established in September 1986 to protect the marine system.²⁾ The implications are that visits of tourists are limited to certain parts of the marine sea. In addition, fishing is being controlled by rules, fishing zones, fishing periods and types of nets. Besides tourism and fishing, a third type of negative impact of human activity on the marine system is occurring, namely through flows of pollution and waste generated by the island population, tourists and economic activities. The model will concentrate on nitrogen and phosphorus derived from tourist and population numbers, and certain economic activities. Additional derived indicators for the consequences on living conditions and organic materials in the marine environment are BOD (Biological Oxygen Demand) and chlorophyll.

The natural environment provides several services and goods to the socio-economic system. Both the terrestrial and marine ecosystems, in particular the existence of seals and dolphins, add to the attractiveness of the areas for tourists. Besides these ecological characteristics, the area provides many nice beaches and watersport facilities. The terrestrial system supplies firewood and resin (for Greek wine), while goats, providing meat and milk (used for making cheese), are herded on the scrub and rock land. And, as already mentioned, the marine system provides fish for fisheries catch.

The past directions of development of the three main islands Skiathos, Skopelos and Allonisos have been greatly influenced by the pattern of tourism. However, the development stages of the three islands differ significantly. Skiathos has a long history as a holiday resort for Greek citizens, mainly those coming from the two largest Greek cities Athens and Thessaloniki. Though originally characterized by a reputation of richness and exclusiveness, it is currently functioning as an attractor for various categories of Greek and foreign tourists. On Skopelos, tourism has developed somewhat later, and it is known to be more peaceful. It may be considered at a stage in between those characterizing Skiathos and Allonisos. This latter island is especially quiet, due to a relatively large natural area and a late development of commercial tourism activities only in recent years (since 1980). In the model, special attention is devoted to the consequences of tourism for Allonisos. This means more detailed

²⁾ This was part of recovery plans in line with a resolution on the protection of the Monk seal which was passed by the European Parliament in 1984.

Table 2

Estimated tourist data for the three main islands (1985; on the basis of data from questionnaires, and Frantzi and Despotakis [9]); employment in man years; price level of tourism related to Allonisos.

	Skiathos	Skopelos	Allonisos
Accommodation (number of beds)	1921	1006	535
Tourist-nights	120,000	40,000	20,000
Employment	325	117	65
Relative price level of services in tourism	131	115	100

attention to its economic activities and endogenous development mechanisms in tourism activities and concern for their interactions with the terrestrial system. Table 2 gives relevant *tourism data* for the three islands. From these data and the respective population levels and land areas, we can derive indicators of tourism pressure. Skiathos has then the highest density of tourist-nights per capita (± 23.7) as well as per square meter of land (± 2.4). Allonisos comes second with regard to the first of these two pressure indicators (± 12.3), but last in terms of the other (± 0.24) (for Skopelos, these indicators have values of 9.5 and 0.42, respectively). More details on the structure of the economic system will be given in the presentation of the model.

The island economies are rather small-sized. The following economic sectors can be distinguished: local services, fishery, agriculture, public sector, construction and two tourism-based sectors (accommodation and services). Trade and transport are arranged by mainland firms, leaving no special benefits for the local population other than via the local services. This sectoral disaggregation is based on a combination of considerations: labour market operations, interdependencies between activities, and economic–environmental relationships.

In table 3, we list estimated figures of *value added per sector and island*. Especially the labour market is crucial for the operation of the economy, since it provides the opportunities and constraints for specific sectoral developments. The labour market shows competition for labour within certain categories of activities, e.g. agriculture and fishery. These two latter activities are determined to a large extent by labour remaining after other types of jobs have been fulfilled. A strong pull force is especially generated by the tourism activities. More information will be given in our discussion of specific modules in the next section.

The Northern Sporades provide an interesting case for testing integrated economic–ecological modelling on a regional scale, and for performing scenario analysis of tourism and economic development. The possible conflict between an (one-sided)

Table 3
Estimated sectoral value added figures per island
(1985; source: Frantzi and Despotakis [9]).

× million Greek drachme	Skiathos	Skopelos	Allonisos
Accommodation	393	115	62.5
Tourism services	3760	987	400
Construction	84	42	131.5
Local services	287	240	92
Agriculture	3.1	3.6	57
Fishery	8.8	10.5	83
Total	4534.9	1397.1	1026

economic development focused on tourism can give rise to undesirable long-term outcomes, both in terms of natural and economic consequences, especially in view of the nature conservation directed at both land and marine ecosystems.

5. Model structure

Here, we will explain the structure of the model that was designed to obtain insight into the long-term development of tourism, the island economies and the natural environment. The model is descriptive, formulated as a set of differential and auxiliary equations, and used for dynamic simulation based on well-chosen development and policy scenarios. The dynamic structure is based on (dynamic) *stock-flow* relationships. The stock variables are described in balance equations: they are increased by ingoing flows and decreased by outgoing flows. All but the stock variables are either exogenous or based on other stock and flow variables. This means that the model is to some extent set up according to causal mechanisms. Especially from the dynamic and development point of view, this is attractive. For the present model, the base year is 1985, the time horizon is 20 years, and the time resolution is years.³⁾ For further details, the reader is referred to Van den Bergh [3]. The model's endogenous variables will be discussed hereafter. The exogenous variables are given in the appendix. The variables linking islands among each other, as well as those linking the region with the outside world, will also be discussed below. A less detailed and generalized theoretical analogue of the present environmental-economic development model is contained in Van den Bergh and Nijkamp [5].

³⁾ The dynamic simulation package Stella (Richmond et al. [21]) was used to solve the model over time as a set of differential equations.

Figure 2. Structure of the economic-environmental model.

In figure 2, the *overall structure* of the model is shown, which is designed according to interactive modular components. On this highest modular level, descriptions are given of the three main island economies, the socio-economic relationships with the outside world, the influence on the nearby area Pillion, and the impact of the mainland on the marine system. The three main islands in the region are separately treated for three reasons. First, their development levels differ. Second, only the Allonisos module includes a terrestrial submodule with a description of land use and natural vegetation cover. Finally, Allonisos receives special attention in the study from the policy perspective. The economy and people modules are set up for each of the islands.

In the "*economic activities*" module, the economic sectoral classification is adapted to sector-environment interactions. The sectoral structure, income composition, and important determinants of sectoral development and production are set up in a similar way for each island, although in somewhat more detail for Allonisos. The following sectors are distinguished: an accommodation sector including hotels, bungalows and pensions; a tourist service sector including restaurants, bars, rental services and souvenir shops; a private service sector; a construction sector for investments in private and public activities; two resource-based sectors: agriculture and fisheries; public services such as education, health care, administration, and police; and utilities – focused on water pumping – and infrastructure.

The model control variables are: the investment in accommodation (*inv_acc*), a dummy to define investment factors in local fishery (*dum_fish*), a dummy for tourism in the marine park (*marine_tourist*), a dummy to relate fish catch to determinant factors (*sust_fishing*), a dummy to define the change in tourism (*dum_tour*, *dum_tournat*,

dum_tour1, dum_tour2), and a policy instrument to simulate traditional agriculture (agric_policy). The values of and conditions on the control variables for different scenarios will be given in table 4 in section 6.

The equations generating the endogenous variables are presented below. Because of the large number of variables, their names are chosen as expressively as possible. Time subscripts are not included, although the model is dynamic. Most relationships are between variables at a single point in time, for the entire period of analysis, i.e.: $y(t) = f(x(t), u(t), t)$, with $y(t)$ an endogenous variable, $x(t)$ a vector of all other endogenous variables, $u(t)$ a vector of all control variables, and t a variable indicating simulation time. Dynamic equations are indicated by variables change_z, where the change is described in the variable z . The representation here replaces the formal relationship $dz/dt = in_z - out_z$, where the endogenous variables in_z and out_z are functions of other variables at time t . In other words, change_z refers to a change per unit of time in a stock variable z .

Unless stated otherwise, all equations refer to Allonisos; terms or subscripts ski, sko and pil given in between brackets immediately after an equation denote that the same equation is used in the modules for Skiathos and Skopelos; initial conditions in dynamic (stock-flow) relationships for Skiathos and Skopelos are also indicated in between brackets, by ski= and sko= followed by a number; INIT(.) is the initial value of the variable between brackets; MAX(.,.) and MIN(.,.) are functions which give the maximum and minimum of two values, respectively; TIME is a time variable; RANDOM is a randomly generated number between 0 and 1; and IF..THEN..ELSE is used for conditional statements; ^ indicates a power function.

Some activities are modelled around a fixed input, e.g. capital such as buildings and machines, as a starting point. The *supply of hotel accommodation* is based on a dynamic equation reflecting investment minus depreciation:

$$\text{change_acc} = \text{inv_acc} - \text{deprec_acc}, \text{INIT}(\text{acc}) = 535, \text{ski} = 1921, \text{sko} = 1066),$$

where *investment* is given by

$$\begin{aligned} \text{inv_acc} = & \text{MAX}(0, \text{MIN}(\text{max_acc} - \text{acc}, \text{deprec_acc} + \text{MAX}(0, \text{growth_tourism}) * \text{acc} \\ & + \text{exog_acc} + \text{endog_acc}), \text{deprec_acc} + 1 * 0.05 * \text{acc} + 0 * 0.05 * \text{acc}) (\text{ski}, \text{sko}), \\ \text{exog_acc} = & 0 \end{aligned}$$

and *depreciation* follows

$$\text{deprec_acc} = 0.0125 * \text{acc}.$$

As is seen above, the investment of accommodation can be divided into a sector-endogenous and an exogenous part. The endogenous part is formulated as follows.

$$\begin{aligned} \text{endog_acc} = & \text{IF}((\text{occupation_1_acc} > 0.3) \text{ AND } (\text{profit_1_acc} > 0.3)) \text{ THEN} \\ & \text{MAX}(0.8 * \text{profit_1_acc}, 110) \text{ ELSE } 0 \end{aligned}$$

```

occupation_1_acc = DELAY(occup_acc,1,0.2054)
occup_acc = sales_acc/(acc*182)
profit_1_acc = DELAY(profit_acc,1,7800000);
profit_acc = 0.3*(price_acc*sales_acc)
max_acc = 2*600; max_acc_ski = 1.5*1921; max_acc_sko = 1.5*1006

```

The *supply of public utilities* depends on investment:

```

change_utilities = inv_util, INIT(utilities) = 100*365
inv_util = -(utilities - capacity_grdwater)*d

```

Changes in the *stock of fishery vessels* are modelled as investment minus depreciation:

```

change_tradit_vessels = inv_vess-deprec_vess, INIT(tradit_vessels) = 211 (ski = 35, sko = 30)
inv_vess = deprec_vess + dum_fish*MIN(0.02,growth_tourism)*tradit_vessels (ski, sko)
deprec_vess = 0.033*tradit_vessels

```

The *activity levels in the tourist sectors* are determined by the number of days/nights spent by tourists, determined in the “*people*” module. The activity level in local services is determined by the population level and in public services by both tourist and population levels, given by the “*people*” module:

```

change_popul = (migration + pop_growth)*popul (ski, sko),
INIT(popul) = 1621, (ski = 5064, sko = 4226)
change_tourists = dum_tour*MAX(0,tourist_reaction)*(dum_tournat*tourism_nation +
(dum_tour1 + dum_tour2*0.03)*tourists*
MIN(1,0.5*max_acc*180/tourists) -
MIN(0,tourist_reaction)*0.05*tourists,
INIT(tourists) = 25000, (ski = 120000, sko = 40000, pil = 0),
dum_tour = IF car_cap_tour <= tourists THEN 0 ELSE 1
change_tourists_ski = tourism_nation*tourists_ski*
MIN(1,0.5*180*max_acc_ski/tourists_ski - 1) (ski)

```

Construction activity (“*sales*”) depends on the expansion of hotels, and the increased demand for housing, given by the “*people*” module

```

sales_constr = (4*(incr_sec_hous + incr_hous)*10 + 0.5*inv_acc*10 +
0*2.5*10-8*tot_inc_1)/0.4
sales_constr_i = (4*inc_hous_i + 0.5*inv_acc_i + a_i)*10/0.4,
i = ski,sko,a_ski = 2*a_sko = 28

```

Agricultural produce is dependent on a production function with a mix of economic and natural factors:

```

prod_agric = 0.4*cultiv_land*((labour_agric)**0.5)*(1 - EXP(-water_agric/1000))*(1 +
    agr_policy*agr_effic) (ski, sko)
agric_effic = 1 + 0.05*TIME
cultiv_land_ski = 500
cultiv_land_sko = 1000

```

The *total sales* in other activities is as follows:

```

sales_acc = IF tourists > 182*acc THEN 182*acc ELSE tourists (ski, sko)
sales_locserv = (92*106/INIT(popul))*popul*(tot_inc_1/INIT(tot_inc_1))/0.3
sales_locserv_ski = (56756)*popul_ski/0.3 (sko)
sales_servtour = (4*108/0.3)*(tourists/INIT(tourists)) (ski = 24*108, sko = 8*108)
publ_services = (57*106/INIT(popul))*popul
publ_services_ski = (57*106/INIT(popul_ski))*popul_ski*(5064.5/1650)
publ_services_sko = (57*106/INIT(popul_sko))*popul_sko*(4225.5/1650)

```

Costs of public activities are:

```

costs_public_serv = 0.2*publ_services;
cost_infra = (0.05*5500 + 200)*land_infra;
cost_water = (1500*import_water + 150*utilities - 150*demand_water)*0.2

```

Government budget is assumed to be balanced at all times:

```

govern_balance = (tax_income + national_subsidy) - (cost_infra + cost_water +
    costs_public_serv)
tax_income = taxprof_rate*tot_valad
taxprof_rate = 0.27

```

The “*people*” module also includes equations for demography, housing development, tourist flows and operation of the labour market. Population change falls apart into growth and migration. Housing is disaggregated into primary and secondary houses. The stock of *houses* depends on population and tourist levels, based on the demand for rented rooms and second houses:

```

pop_incr = pop_growth + migration
pop_growth = 0.015 (ski = 0.0056, sko = 0.003)
migration = - 0.0027; migration_ski = 0.0015; migration_sko = 0.0015
hous = hous + dt*(incr_hous), INIT(hous) = 497 (ski = 1800, sko = 1200)
sec_hous = sec_hous + dt*(incr_sec_hous), INIT(sec_hous) = 100
incr_hous = (incr_pop/popul)*hous (ski, sko)

```

Derived from population and tourist levels are several *use and environmental pressure indicators*:

```

demand_water = 27.375*(popul + 1.5*tourists/180) (ski, sko)
congestion = 100*(popul + 3*tourists/20)*INIT(natural_vegetation)/(natural_vegetation*
(INIT(popul) + 3*INIT(tourists)/20))
dust = 100*(0.4*sales_locserv + 0.3*publ_services + 0.6*sales_servtour + 1*sales_acc +
2.1*sales_constr)/(0.4*INIT(sales_locserv) + 0.3*INIT(publ_services) +
0.6*INIT(sales_servtour) + 1*INIT(sales_acc) + 2.1*INIT(sales_constr))
envir_stress = 100*SQRT((5*tourists/20 + popul)/(5*INIT(tourists)/20 + INIT(popul)))
noise = 100*(2*sales_constr + 0.003*popul + 0.006*tourists)/(2*INIT(sales_constr) +
3*INIT(0.001*popul + 0.002*tourists))
road_congestion = ((tourists/182) + popul)/land_infra
road_congestion_sko = ((tourists_sko/180) + popul_sko)/infra_sko
import_water = demand_water-utilities;
imp_water_rate = import_water/demand_water
sewage = 100*(popul + 1.5*tourists/180)/INIT(popul) + 1.5*INIT(tourists)/180

```

Labour supply is determined by population size (indirectly including effects of migration and seasonal commuting), exogenous trends in participation rates, and a combination of productivity and working hours. As mentioned in the previous section, labour pull occurs in some sectors, and is generated within the “economic activities” module. The remaining labour supply, determined in the “people” module, an agricultural incentive policy and competition for labour by a mainland fishery industry, determine agricultural and fishery activity levels.

```

change_mainl_fish = inv_trat, INIT(mainl_fish) = 2
inv_trat = 0*(subsidizing_EC + exog_trat)*mainl_fish
exog_trat = 0

```

Then *labour allocation* between demanding and remaining sectors, and unemployment can be determined as follows:

```

labour = participation*popul*(505 + 50)/INIT(popul)
labour_agric = (1-agric_policy)*labour_II*(45/INIT(labour_II)) + agric_policy*
MIN(agric_incentive, labour_II)
labour_agric_ski = MAX(MIN(0.5*labour_ski, labour_II_ski-labour_vess_ski),
0.01*labour_ski) (sko)
labour_II = MAX(0, labour-empl_acc-empl_rentroom-empl_servtour-empl_constr -
empl_locserv-empl_publicserv)
labour_ski = 0.31*popul_ski; labour_sko = 0.28*popul_sko
labour_vess = MAX(0, MIN(105*tradit_vessels/INIT(tradit_vessels), labour_II -
labour_agric - 0.1*empl_trat))
labour_vess_ski = MIN(2*tradit_vessels_ski, labour_II_ski) (sko)
empl_acc = 65*MIN(SQRT(sales_acc/INIT(sales_acc)), SQRT(acc/INIT(acc)))*
MIN(1.8*occup_acc) - 0*(agric_incentive - 45)*65/(115 + 65)

```

```

empl_acc_ski = 5*65*SQRT(acc_ski/INIT(acc_ski))
empl_acc_sko = 1.8*65*SQRT(acc_sko/INIT(acc_sko))
empl_constr = 15*SQRT(sales_constr/INIT(sales_constr)) (ski = 30, sko = 39)
empl_locserv = 80*SQRT(sales_locserv/INIT(sales_locserv)) (ski = sko = 200)
empl_publicserv = 30*SQRT(publ_services/INIT(publ_services)) (ski = sko = 45)
empl_rentroom = 50 (ski = 150, sko = 200)
empl_servtour = 115*SQRT(sales_servtour/INIT(sales_servtour)) –
                0*(agric_incentive – 45)115/(115 + 65)
empl_servtour_ski = 575*SQRT(sales_servtour_ski/INIT(sales_servtour_ski)) (sko = 230)
empl_trat = (100/INIT(mainl_fish))*mainl_fish
unemployment = MAX(labour_ll – labour_vess – labour_agric – 0*0.1*empl_trat –
                    1*10-4, 0) (ski, sko)
unemployment_rate = MAX(0, unemployment/labour – 0.001) (ski, sko)

```

The description of *socio-economic relationships in Pillion* is kept very simple. It includes only agricultural and general tourist sector activity. These are assumed to experience spillover effects of development of the three main islands, given by the respective “economic activities” modules. In addition, they may be subjected to sectoral incentive policies:

```

change_agric_Pil = MIN(exog_agr_Pil, 0.3*popul_Pil-addit_tour_Pil/40), INIT(agric_Pil) = 0
change_tourists_Pil = MIN(exog_tour_Pil + spillover_tour_Pil, 40*0.3
                          *popul_Pil-tourist_Pil)INIT(tourists) = 0
spillover_tour_Pil = 0.1*(MAX(0, tourists_ski – 0.4*180*max_acc_ski) +
                          MAX(0, tourists_sko – 0.4*180*max_acc_sko) + MAX(0, tourists –
                          0.4*180*max_acc))
exog_agr_Pil = 0 + 100*policy_Pillion
exog_tour_Pil = 0 + 100*policy_Pillion
popul_Pil = 600;

```

The main driving force behind economic development is *tourism*. The structure of the tourist module is shown in figure 3. The number of tourists is determined by a regional trend, which is to some extent following a national pattern based on implicit assumptions on international development in tourism demand. A local attraction mechanism is supposed to depend on regional economic and environmental amenities as well as several disamenities. This local attraction is altered by regional development, and through the impact of tourism on regional development provides a feedback mechanism from economic and environmental conditions, generated by the “economic activities”, the “terrestrial system”, and the “marine system” modules, to tourist growth. Such a mechanism may, for instance, cause a curbing effect on initially high growth in the number of tourists. The equations belonging to the tourism module are as follows:

Figure 3. Sub-module for the development of tourist demand.

```

amenities = 100*(0.25*quality_seawater/INIT(quality_seawater) +
0.1*land_diversity/INIT(land_diversity) +
0.15*natural_vegetation/INIT(natural_vegetation) +
0.2*adult_seals/INIT(adult_seals) +
0.2*((INIT(tourists)/tourists)**0.3) + 0.1*acc/INIT(acc))
disamenities = 100*(noise/INIT(noise) + congestion/INIT(congestion) +
road_congestion/INIT(road_congestion))/3
attraction = 100*SQRT((1 + amenities*INIT(disamenities))/
(1 + INIT(amenities)*disamenities))
growth_tourism = addition_tour/tourists (ski, sko)
tot_tourists = tourists + tourists_ski + tourists_sko

```

Prices of most goods and services are assumed constant and in real terms. This may be regarded as a long run equilibrium condition. It should be noted that since the model provides for a description of interrelated economic and environmental systems, it is not possible to simply extend price-endogenous models – ideally based on the general equilibrium framework – to deal with such integrated research questions. However, to introduce some important long run price movements, the price level of tourist services and accommodation on Allonisos and Skopelos are allowed to change over time. They converge within a specific time period to the respective price levels of Skiathos. This means that differences in the initial price level of tourism services between the three islands – as shown in table 2 – are assumed to disappear in the long run:

```

price_acc = if TIME < 10 THEN 1300 + TIME*(price_acc_ski - 1300)/9 ELSE
price_acc_ski
price_acc_ski = 1700
price_acc_sko = IF TIME < 7 THEN 1500 + TIME*(price_acc_ski - 1500)/6 ELSE
price_acc_ski

```

```

price_tourserv = IF TIME < 10 THEN (3000) + TIME*(price_tourserv_ski – 3000)/9 ELSE
                price_tourserv_ski
price_tourserv_ski = 3200 + 1500
price_tourserv_sko = IF TIME < 4 THEN (3700) + TIME*(price_tourserv_ski – 3700)/3
                    ELSE price_tourserv_ski
    
```

The *income (value added) of various sectors* is given by the following equations:

```

tot_valad = sum of valad_i + pensions + valad_trade (ski, sko)
valad_acc = price_acc*sales_acc*50/26;
valad_agric = (57*106/INIT(prod_agric))*prod_agric*price_agr
valad_constr = 0.4*0.2*(price_constr*sales_constr);
valad_locserv = 0.3*sales_locserv
valad_servtour = 0.3*sales_servtour*(price_tourserv/INIT(price_tourserv))
valad_trade = ((sales_locserv + sales_servtour)/(INIT(sales_locserv) +
                INIT(sales_servtour)))*380*106 (ski, sko)
valad_vess = (83*106/INIT(catch_vess))*catch_vess (ski, sko)
pensions = 176*106*popul/1621; (ski, sko)
    
```

The *determinants of development and growth* range from the number of tourist visits (for tourist sectors), profit levels (tourist sectors), economic policies (e.g. aimed at agricultural development), environmental management rules (e.g. sustainable fishing), to the feedback of ecological limits. For some of the activities capacity, physical or biological (e.g. land and water for agriculture, fish stocks for fishery) are taken into account. The latter two limits are generated by the terrestrial and marine system modules:

```

capacity_grdwater = 50;
car_cap_agr = 5970;
car_cap_tour = 15562469*14;
car_cap_urb = 45020
    
```

A *terrestrial module* represents structural long-term economic–environmental interactions that occur through land transformation (discussed in section 4). Dependent variables are land areas with one type of vegetation or land use. Their driving forces, generated by the “economic activities” and “people” modules, are: land use by agriculture, which transforms areas with natural vegetation into cultivated land; grazing by cattle, encouraging the transformation of one type of scrubland into another; and urban growth via new houses, tourist sectoral investment, and infrastructure development, mainly transforming agricultural land around existing urban areas. Natural processes of exchange are described, between different types of vegetation (forest, maquis, and garrigue). Tourism, generated by the “people” module, has a direct effect on these processes through increased probabilities of fires. The processes and exogenous

factors that affect the composition of natural areas consist of four categories. A physical constraint based on data on altitudes and ground structure sets limits to changes in land uses. A land diversity index is generated to serve as an input to the tourism module:

```
change_bare = fire_f + fire_m + out_lm_b - out_b_lm - out_b_urb,
              INIT(bare) = 3390 + 2270
change_low_maquis = out_m_lm - out_lm_b + out_b_lm - out_lm_m - out_lm_ag -
                    out_lm_urb, INIT(low_maquis) = 29650
change_maquis = out_f_m - out_m_lm - fire_m + out_lm_m, INIT(maquis) = 32950
change_forest = - out_f_m - fire_f, INIT(forest) = 9460
change_urb_land = out_b_urb + out_lm_urb + out_cult_urb, INIT(urb_land) = 2250
                  (ski = 3400, sko = 3900)
change_cultivation_land = out_lm_ag - out_cult_urb, INIT(cultivation_land) = 1920
landuse_acc = (1-policy_floors)*acc*20/1000
```

These equations are supported with *descriptions of causation processes*. These include weather processes, agricultural influences, and urban expansion. Furthermore, as a specific natural process of importance for natural vegetation in a seasonally dry and hot environment, such as the Mediterranean, also spontaneous fires are included. As a specific agricultural factor, grazing animals are included:

```
out_b_lm = recolonizatn_factor*0.1*bare
out_b_urb = urb_expansion/3
urb_expansion = dum_urb*(2*DELAY(landuse_acc,1,10.7) + land_policy*0.02*
                    urban_land + 0.2*pop_incr*urban_land)
dum_urb = IF car_cap_urb <= urban_land THEN 0 ELSE 1
out_cult_urb = urb_expansion/3
out_f_m = IF rain_wind_fire < 500 THEN 0.005*forest + 0.004*RANDOM*forest +
            0.05*grazing ELSE - 0.01*forest + 0.05*grazing + 0.002*RANDOM*forest
out_lm_ag = dum_agr*MAX(0, labour_agric*INIT(cultivation_land)/INIT(labour_agric) -
                    cultivation_land)
dum_agr = IF car_cap_agr <= cultivation_land THEN 0 ELSE 1
out_lm_b = IF rain_wind_fire < 500 THEN 0.02*low_maquis*RANDOM + 0.5*grazing
            ELSE 0.01*low_maquis*RANDOM + 0.5*grazing
out_lm_m = 0.05*recolonizatn_factor*low_maquis
out_lm_urb = urb_expansion/3 out_m_lm = IF rain_wind_fire < 500 THEN
            0.045*maquis*RANDOM + grazing*0.4 ELSE 0.01*maquis*RANDOM +
            grazing*0.45
disaster_fire = IF TIME = 10 THEN 1 ELSE 0
fire_f = IF random_fire_f < 0.01 THEN 0.25*RANDOM*forest ELSE
            fire_m_to_f*0.1*RANDOM*forest
```

```

fire_m = IF random_fire_m < 0.025 THEN RANDOM/2*maquis ELSE
        disaster_fire*RANDOM/2*maquis
fire_m_to_f = IF fire_m > 0 THEN 1 ELSE 0
rain_wind_fire = 500 + 100*NORMAL
random_fire_f = MIN(RANDOM*INIT(tourists)/tourists,1)
random_fire_m = MIN(RANDOM*INIT(tourists)/tourists,1)
storm = IF RANDOM > 0.95 THEN 1 ELSE 0
grazing = 10*labour_agric/INIT(labour_agric)

```

The “*marine system*” module consists of a water quality component and an ecological system description. Nitrogen and phosphorus emissions are determined by population and tourist levels, generated by the “people” module, and impact indirectly upon BOD and chlorophyll in the water along the coastline:

```

change_nitrogen = in_N – out_N + balance_N, INIT(nitrogen) = 1836964
change_phosphorus = in_P – out_P + balance_P, INIT(phosphorus) = 457934
change_BOD = in_BOD – out_BOD + balance_BOD, INIT(BOD) = 4567050
change_chlorophyll = in_chlor – out_chlor = balance_ch, INIT(chlorophyll) = 6951
balance_BOD = – BOD;
balance_ch = – chlorophyll;
balance_N = – nitrogen;
balance_P = – phosphorus;
conc_chloro = chlorophyll/harb_vol;
conc_chlor_N = 10^(1.5*LOG10(conc_N) + 1.65);
conc_chlor_P = 10^(0.94*LOG10(conc_P) + 2.05);
conc_N = (nitrogen/harb_vol/1000);
conc_P = (phosphorus/harb_vol/1000);
in_BOD = (inhab_days*45 + (1 – t_biol_treat)*tourists*45)*0.75 + olive_presses_S
olive_presses_S = IF TIME – 2*INT(TIME/2) = 0 THEN
                    MIN(10,10*labour_agric/INIT(labour_agric)) ELSE 0
inhab_days = popul*122
in_chlor = MIN(conc_chlor_N, conc_chlor_P)*harb_vol
in_N = ((1 – t_biol_treat*0.5)*tourists + inhab_days)*9.2
in_P = ((1 – 0.6*t_biol_treat)*tourists + inhab_days)*2.3
out_BOD = (0.5 + harb_flush)*BOD
out_chlor = harb_flush*chlorophyll + chlorophyll*0.5
out_N = harb_flush*nitrogen;
out_P = phosphorus*harb_flush
harb_flush = 0.1
harb_vol = 100000

```

The *water quality* has a slight effect upon the marine ecology. The ecosystem is modelled as a food chain, with the Monk seal predating on two types of fish (see

section 4). Lobster and two classes of fish are fished. Vessels from three islands and the mainland generate a certain amount of fishing effort, determined within the “economic activities” module, which is an important factor of catch. There are two other determinants. One is the sum of the sizes of the four stocks of fish and lobster species being subjected to fishing. The other is the constraint on catch to realize sustainable fishing patterns. This may be operationalized by restrictions on types of nets, fishing periods and zones:

```

change_fish_i = incr_f_i - catch_f_i - seals_i, i = 1,2, INIT(fish_1) = 36600, INIT(fish_2)
               = 94280
change_fish_3 = incr_f_3 - catch_f_3, INIT(fish_3) = 1288540
change_lobster = incr_lob - catch_lob - seals_lob, INIT(lobster) = 57550
change_young_seals = births - deaths - maturity, INIT(young_seals) = 16
change_adult_seals = incr_sl - decr_sl, INIT(adult_seals) = 32
seals_1 = IF fish_1 < INIT(fish_1)/2 THEN 0 ELSE ((fish_1/INIT(fish_1))**1.7)*
          demand_nut/2
seals_2 = IF fish_2 < INIT(fish_2)/2 THEN 0 ELSE ((fish_2/INIT(fish_2))**1.7)*
          0.9*(demand_nut - seals_lob - seals_1)
seals_lob = IF lobster < INIT(lobster)/2 THEN 0 ELSE ((lobster/INIT(lobster))**1.7)*
            demand_nut/2
births = 1*(adult_seals)/2*(1 - urb_exp_north)*(1 - marine_tourist)*(nut_balance)**1.5
deaths = storm*births + 0.4*young_seals;
incr_f_1 = fish_1*(46120 - fish_1)/46120;
incr_f_2 = fish_2*(14824*8 - fish_2)/(14824*8)
incr_f_3 = fish_3*(202605*8 - fish_3)/(202605*8)
incr_lob = lobster*(72476 - lobster)/72476
incr_sl = young_seals/2
demand_nut = adult_seals*100 + young_seals*50
decr_sl = 0.165*adult_seals + 0.1*(adult_seals*adult_seals/32)
nut_balance = IF (nut_seals - demand_nut) > 0 THEN 1 ELSE
              1 - (demand_nut - nut_seals)/demand_nut
nut_seals = seals_1 + seals_2 + seals_lob

```

Interaction of *fishery activities* of separate islands and the mainland occurs by way of competition for the same fish, represented by the following equations. In that process, sustainable fishing is included as a theoretical possibility, regardless of how it is effectuated.

```

fish_all = fish_1 + fish_2 + fish_3 + lobster
actual_catch = catch_F_1 + catch_F_3 + catch_F_2 + catch_lob
catch_f_i = MAX(0, MIN(a_i*(fish_i - seals_i), (fish_i/fish_all)*tot_fish_catch)), i = 1,2,lob,
a_1 = 0.7, a_2 = a_lob = 0.75

```

```

catch_f_3 = MAX(0, MIN(0.75*fish_3, (fish_3/fish_all)*tot_fish_catch))
catch_vess = tot_fish_catch*MIN(tradit_vessels, labour_vess/2)/tot_fish_effort (ski, sko)
tot_fish_effort = MIN(tradit_vessels, labour_vess/2) + MIN(tradit_vessels_ski,
    labour_vess_ski/2) + MIN(tradit_vessels_sko, labour_vess_sko/2) +
    mainl_fish
sust_use = INCR_F_1 + INCR_F_2 + INCR_F_3 + INCR_lob-seals_1-seals_2-seals_lob
tot_fish_catch = (1-sust_fishing)*(7.25235*10-4*FISH_all*EXP(1.18*
    LOGN(tot_fish_effort))*fishing_efficiency) + sust_fishing*
    MIN(7.25235*10-4*FISH_all*EXP(1.18*LOGN(tot_fish_effort))*
    fishing_efficiency, sust_use)

```

Remaining equations relate to *indicator equations*:

```

GIP_resident = (tot_valad - valad_trade)/popul
quality_seawater = 100*(0.5*INIT(BOD)/BOD + 0.5*INIT(chlorophyll)/chlorophyll)
land_diversity = 100*(10*forest + 15*maquis + 12*low_maquis + cultivation_land +
    2*sqrturban + bare)/10*INIT(forest) + 15*INIT(maquis) +
    12*INIT(low_maquis) + INIT(cultivation_land) + 2*INIT(sqrturban) +
    INIT(bare))
natural_vegetation = 1*(maquis + forest + low_maquis)
index_attraction = attr_1/INIT(attr_1)

```

This concludes the formal presentation of the model.

6. Scenario analysis

Two possibly *conflicting objectives* which have to be resolved for the Sporades region are *regional economic development* dominated by tourists, and environmental protection of the *terrestrial and marine ecosystems*, especially conservation of the Monk seal colony. A constraint to the first objective could be the economy's high dependency on one sector, namely tourism. Therefore, anything with an adverse impact on tourism provides a threat to future income. Economic and human activities cause a range of environmental impacts: water pollution, loss of landscape values, loss of traditional values (culture), transformation of old villages, congestion (litter, noise, recreational values), and over-fishing. These effects could adversely impact future tourism and threaten economic development. They are also directly contradictory to the second objective. A constraint to the second objective is partly overlapping with that to the first one: growth of certain activities and the size of human impacts may not be sustainable from a nature conservation point of view.

Scenarios are designed by focusing on policies and exogenous patterns or events. Several types of policy actions can be taken: environmental, conservation, economic, infrastructural and social programs, and even changes in institutional

arrangements. Three types of exogenous patterns or events can be distinguished, namely internal socio-economic, external economic, and natural events. The future development of the Sporades islands may range from an extrapolation of present trends to strong sectoral deviations of these trends due to environmental or economic opportunities, constraints and policies. The following eight scenarios are used to deal with the most obvious and important policy and development options for the Sporades islands:

- (1) *Steady growth*: all sectoral growth rates are in line with present trends; tourist numbers continue to grow; tourists are allowed to visit the marine park area.
- (2) *Steady growth and marine park policy*: as (1), but now the tourist flow to the marine park is controlled.
- (3) *Strong growth*: as (2), but with a higher potential growth rate of tourists; tourist control as in (2).
- (4) *Limiting tourism growth*: as (2), but now tourist growth is zero.
- (5) *Sustainable fishing*: as (2), fishing effort is confined to levels for which the stocks of fish are not reduced; tourist control as in (2).
- (6) *Tourist limits and sustainable fishing*: a combination of (4) and (5).
- (7) *Agricultural incentive*: as (2), with work in agriculture, especially cultivation of land, strongly stimulated.
- (8) *Very strong growth*: as (2), but tourist numbers follow a very high growth rate.

Table 4 shows the control variables in the model and their values in each scenario. The numbers in the table correspond to those of the scenarios.

Performance indicators generated by the "economic activities" module will be used to test for economic efficiency, equity, and conservation. Value added and unemployment can be used to test for efficiency, on a sectoral, island or regional level. The testing for equity may pertain to equity between sectors or islands.

As indicators related to *regional development of tourism* may serve the number of tourist-nights spent ("people" module), the land use of accommodation industry ("economic activities" module), and the percentage of drinking water that is imported ("economic activities" module). This import of water depends on the extraction in the region, and the demand based on tourists and local people. The natural and economic aspects related to tourism are summarized in indices for amenities and disamenities based on a set of natural, economic and congestion variables (as explained in figure 3). These latter indices can be regarded as attractiveness indicators for tourism.

As indicators for *terrestrial disturbance and pollution*, we use a congestion index that is based on the total number of tourists and local people, generated within the "people" module, waste particles generated within the "economic activities" module, dependent on certain activity levels such as in construction, and sewage, determined by population and tourist levels.

Table 4

Values of control variables for the various scenarios; scenarios vertically and control variables horizontally.

	Investment in accommodation	Investment in local fishery	Tourist control in marine park area	Catch fishing	Change in no. of tourists	Agricultural (employment) policy
(1)	growth tourism, $\leq 5\%$	growth tourism, $\geq 2\%$	1	effort and stock	national and local	none
(2)	growth tourism, $\leq 5\%$	growth tourism, $\geq 2\%$	0	effort and stock	national and local	none
(3)	growth tourism, $\leq 5\%$	growth tourism, ≥ 2	1	effort and stock	3% + national and local	none
(4)	0	2%	0	effort and stock	0	none
(5)	growth tourism, $\leq 5\%$	growth tourism, $\geq 2\%$	1	$\leq$ regeneration rate	national and local	none
(6)	0	2%	0	$\leq$ regeneration rate	0	none
(7)	growth tourism, $\leq 5\%$	growth tourism, $\geq 2\%$	1	effort and stock	national and local	supply increase 45–145 over 20 years
(8)	growth tourism, $\leq 10\%$	growth tourism, $\geq 2\%$	1	effort and stock	6% + national and local	none

For *land vegetation conservation*, two indicators have been selected: the total area of forest and maquis, and an index for land diversity. These are determined on the basis of the land areas under human control or with different vegetation types, given by stock variables in the “terrestrial” module.

Finally, three indicators, generated in the “marine system” module, were chosen for *marine conservation*, namely adult seals, the total stock of fish, and the quality of marine water. The latter is based on the concentration of nitrogen, phosphorus, and on BOD and chlorophyll.

In the remainder of this section, we will discuss results of scenario analysis based on the model described in the previous section, the eight scenarios mentioned above, and a choice out of the possible indicators mentioned. The performance of economic and tourism indicators for Allonisos will be compared with those for the other islands. The performance of the attractiveness and environmental indicators for tourism on Allonisos will be discussed separately from the environmental indicators for the marine system.

6.1. TOURISM AND ECONOMIC DEVELOPMENT ON ALLONISOS AND THE OTHER ISLANDS

In figure 4, the island patterns of total value added are shown: for Allonisos under four scenarios, namely (1), (6), (7) and (9) (see above); and for the other two

Figure 4. Allonisos economy compared with other islands.

Figure 5. Comparison of unemployment rate on Allonisos under six scenarios.

islands under steady growth. The slow-down observed on some curves is explained by tourism development under stationary growth (see figure 6). Both the national pattern and the environmental feedback through amenities and disamenities are responsible for this. Under strong growth, the size of the economy on Allonisos will approach that of Skopelos, while both will approach that of Skiathos. Scenario (6), which can be considered as reflecting the most strict environmental conservation measures, leads to the slowest pace of growth. The agricultural incentive (scenario (7)) gives rise to a higher growth rate than under stationary growth. This growth is a net

effect of growth on a sectoral level under the respective scenario, and thus captures indirect inter-sectoral effects.

Figure 5 shows the unemployment rates for Allonisos under the various scenarios, which show trends consistent with those in figure 4. It is clear that the environmental scenario (6) generates the highest and an increasing unemployment level over the entire period. Unemployment is also increasing under the stationary growth scenario, especially because supply of labour increases faster than demand, as a result of increased participation (stimulated by clean, simple work in tourism for which little education is necessary), population growth and migration, and seasonal commuting. The agricultural incentive and high growth scenarios (7) and (8) lead to the best performance from the viewpoint of employment. Although growth in production per capita is higher under growth scenario (3) than under agricultural incentive scenario (7), unemployment over time is always higher. This can be explained by noticing that the growth under scenario (3) is dominated by the tourism sectors, where the receipts per unit of labour effort are higher than in agriculture.

Tourists numbers (indicated by total nights spent per year) are shown for Allonisos and Skopelos in figure 6. Under most scenarios, the pattern of growth in the number of tourists is curbed as a result of feedback from attractiveness indicators and changes in national trends. The number of tourists is not allowed to increase under the very strict environmental conservation scenario (6).

Figure 6. Tourist numbers, under different scenarios, of Allonisos compared with Skopelos.

6.2. ENVIRONMENTAL AND ATTRACTIVENESS INDICATORS ON ALLONISOS

A complete characterization of the regional situation at a given time includes, in addition to this economic performance levels of the islands, information on the

Figure 7. Amenities index under scenarios (1) to (4).

Figure 8. Amenities index over time under scenarios (5) to (8).

state of the environment, summarized in the amenities and disamenities, a land diversity index, and the marine ecosystem species. This is even so when only impacts upon economic performance are regarded, especially on tourism development as mentioned before, and on fisheries. Initially, amenities for Allonisos are decreasing under all scenarios, as indicated by an index over time in figures 7 and 8. After some time, we see that under scenarios (3), (4), (5), (7), and especially (8), amenities are increasing. The reason is that economic amenities are included in the index, and they are generated by economic growth in the tourism sectors. This is not the case under scenario (7), with agricultural development and reasonably strong growth (see above).

Figure 9. Monk seal population over time under scenarios (1) to (4).

Figure 10. Monk seal population over time under scenarios (5) to (8).

Only for scenarios (2), (4) and (6), that have some form of tourism regulation in common, does the trend continue to be negative. This is explained by the direct negative attraction effect of the environmental protection measures on tourism, and as a derived effect by the negative impact upon economic amenities (e.g. fewer hotels, fewer shops, less service).

The patterns of a disamenities index, which summarizes congestion indicators, are not shown. All these patterns have positive trends, though very modest ones, under the environmental conservation scenarios (4) and (6). The growth scenarios (3) and (8) show the strongest increases. This means that the positive final parts of the

curves denoting amenities for these scenarios are counterbalanced by increasing levels of disamenities. The ultimate combined effect is reflected by the trends in tourist demand. Essentially, this can be regarded as conflicting development patterns: positive trends of economic amenities, negative trends of natural and congestion amenities, and positive trends of natural disamenities. The final levels can be judged on their capacity for positive versus negative impacts on further economic development and/or nature conservation.

Land diversity indicator patterns over time for Allonisos are all following a downward trend. The strong growth scenario (8) gives rise to the steepest fall of this indicator. Only under scenarios (4) and (6) are stabilized levels attained, namely by restricting negative impacts of tourists, tourism activities, and derived activities (e.g. construction).

6.3. ENVIRONMENTAL INDICATORS FOR MARINE SYSTEM

The patterns of Monk seals are given in figures 9 and 10. Scenarios (2), (4) and (6) perform best, although only under scenario (6) the level of Monk seals is stable over time. This means that the negative effect of fishery and tourists has to be minimized, i.e. restricting tourist entrance in certain marine areas and keeping fish catches below sustainable yield. Fish stocks are depleted in most cases (not shown), except under scenarios (5) and (6), i.e. when sustainable fishing is applied. Scenario (2), which includes the marine park policy of restricting tourist visits to a sensitive marine area, gives better results than the steady growth scenario. Scenario (4), which also limits tourist growth, leads to a decrease in the depletion rate of fish stocks via a derived effect on the fisheries, and consequently to a slow down of the decrease in the population of Monk seals.

7. Conclusions

The case study clearly illustrates the risk of environmental unsustainability of regional development. This is partly due to the open character of the region. External forces related to tourism push the regional economy beyond certain environmental carrying capacity limits. The results in section 6 indicate that, compared to the tourism growth scenarios (3) and (8), the environmental conservation scenarios (4) and (6) give rise to worse performances of indicators of island production and employment and tourism amenities. However, the results for tourism disamenities, as well as for terrestrial and marine system indicators, point in a different direction. The agricultural scenario performs very well in terms of island production, especially employment, but show similar behaviour as the steady growth scenario for the other indicators. From the point of view of environmental conservation, scenarios (2) and (5) can be regarded as behaving worse than scenarios (4) and (6).

The case study shows that formal, dynamic models can give us insight into the operation of long-term processes of tourism and economic development, and economic – environmental interactions on a regional scale. Our model indicates that if the Monk seal is to be protected, policy measures should be directed at restricting both negative environmental impacts of tourism and fishery. Even strict limits on tourism growth may be required, e.g. via land or admittance policy. High unemployment is however likely to result from such policy measures. In order to avoid this, tourism growth may be allowed but should go along with a set of very restrictive measures to prevent negative impacts on fisheries and Monk seals. Further formal modelling work may give more attention to endogenous growth and development processes, labour market processes, and seasonal patterns.

With regard to the structure of models used for integrated research as the one reported here, some improvements are clearly possible. From an economic perspective, it would be attractive, for instance, to use the general equilibrium framework to describe the long run economic activity interactions, resulting in a computable general equilibrium (CGE) type of model. However, it is not clear how one can add (long run) environmental processes and economic–environmental interactions in these models. For this reason, integrated research seems to be confined to more partial approaches from an economic perspective. From an environmental perspective, certainly more detail can be included. However, one is also restricted in this respect as a result of the need to have compatible time and spatial scales in economic and environmental models, at least when the aim is to link them.

Appendix: Model variables

All variables mentioned in section 5 have a time index. Names are chosen so as to reflect the interpretation. The variables are to be interpreted as follows:

acc:	number of beds available in accommodation;
agr:	agriculture;
adult seals:	the number of adult seals in the marine park area;
amenities:	an index of touristic amenities, based on a weighted average of an index for seawater quality around the island, a diversity index of land, the area of natural vegetation, and accommodation capacity;
b:	bare land;
catch_vess:	fisheries catch (kg) per island;
change_name:	representation of dynamic equations by change per unit of time (set for numerical simulation) in the variable name;
congestion:	an index for congestion based on number of people (tourists and local population) and the area with natural vegetation;
constr:	construction activity;
deprec_i:	capital depreciation in sector <i>i</i> ;

disamenities:	an index of touristic disamenities, based on noise, congestion in natural areas and on roads;
dum_i:	dummy variables to include certain carrying capacity limits;
dust:	an index for dust waste generated per year based on the level of sales in the following economic sectors: local services, public services, touristic services, accommodation, and construction;
empl_i:	employment in sector <i>i</i> ;
endog_acc:	endogenous part of investment in the accommodation sector;
envir_stress:	environmental stress indicator;
fish_i:	fish stocks (kg);
GIP_resident:	gross income per resident;
imp_water_rate:	the fraction of total drinking water demand (= use) that is met by import;
incr_pop:	increase in population;
inv_i:	investment in sector <i>i</i> ;
labour_i:	demand for labour in sector <i>i</i> ;
land_diversity:	an index of land diversity based on the area of land covered with forest, maquis and low maquis, the area of bare land, the area of land used for agricultural cultivation, and the size of the urban area;
lm:	land area with low maquis vegetation;
landuse_acc:	the area of land used for commercial accommodation purposes;
m:	land area with maquis vegetation;
natural_vegetation:	the total area covered with forest, maquis and low maquis;
publ_services:	public services;
quality_seawater:	an index of seawater quality around the island, based on biological oxygen demand (BOD) and concentrations of nitrogen, phosphorus and chlorophyll in the water;
sec_hous:	number of second houses;
sewage:	an index for sewage waste based on the number of people (tourists and local population);
tot_fish_catch:	fish catch based on effort, stock of fish, and sustainable use feedback;
tot_fish_effort:	effort in fishery based on labour and capital, three islands and the mainland;
tot_tourist:	total number of tourists in the Sporades region in a specific year;
tourists:	the number of tourist days;
utilities:	water extraction capacity;
unemployment_rate:	the rate of unemployment;
urb_expansion:	urban expansion;
valad_i:	value added in sector <i>i</i> .

Exogenous variables are assigned time paths over the simulation period. These variables include *agric_incentive*, *fishing_efficiency*, *incr_sec_hous*, *inv_util*, *national_subsidy*, *participation*, *recolonization_factor*, *rooms_rent*, *rooms_rent_ski*, *rooms_rent_sko*, *tourism_nation*, *tourist_reaction*, *t_biol_treat*.

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