Analysis and Evaluation of Ecosystem Resilience: An Economic Perspective

Lucia Vergano and Paulo A.L.D. Nunes

NOTA DI LAVORO 25.2006

FEBRUARY 2006

SIEV – Sustainability Indicators and Environmental Valuation

Lucia Vergano, *Department of Public and Environmental Economics, University of Pavia*
Paulo A.L.D. Nunes, *Department of Economics, University of Venice and Fondazione Eni Enrico Mattei*

Analysis and Evaluation of Ecosystem Resilience: An Economic Perspective

Summary

This paper focuses on the analyses and evaluation of resilience anchored in an economic perspective. Resilience, as well as most of the benefits provided by ecosystems, is not priced on current markets. However, this does not mean that resilience is of no value for humans. On the contrary, the interest of using an economic perspective, and the respective scientific methodology, will be put forward in terms of resilience relevance for ecosystems' life and functioning, and its impact on human welfare. The economic perspective is anchored in an anthropocentric analysis meaning that resilience is evaluated in terms of provision of natural capital benefits. These, in turn, are interpreted as an insurance against the risk of ecosystem malfunctioning and the consequent interruption of the provision of goods and services to humans. For this analysis, we make use of a conceptual framework so as to identify and describe the different value components of resilience. Finally, we present an illustration that tackles the economic analysis and discussion of resilience benefits in the context of the Venice Lagoon.

Keywords: Ecosystems' resilience, Ecosystems' thresholds, Natural insurance capital, Economic perspective, Economic value

JEL Classification: D62, H41, Q25, Q28, Q51

Address for correspondence:

Lucia Vergano
Università degli studi di Pavia
Corso Strada Nuova, 65
27100 Pavia
Italy
E-mail: lucia_vergano@yahoo.com

1. Introduction

Ecosystems are identified in the ecological literature as ‘biological communities that interact with the physical and chemical environment, with adjacent ecosystems and with the atmosphere’ (Holling *et al*., 1995, p. 54). From an economic perspective, ecosystem functioning and stability are responsible for the provision of a wide range of benefits to humans. Such benefits include, *inter alia*, the maintenance of the genetic library, the direct provision of food, watershed protection and waste assimilation (Folke *et al*., 1996).

In the recent years, anthropogenic pressures are increasingly threatening ecosystem functioning and stability, and thus environmental quality. Increasing rates in the urbanisation trend and demanding land use management regimes, such as intensive monoculture agricultural practices, have contributed to unprecedented impacts on ecosystems. These, in turn, create additional uncertainty with respect to the inter-temporal guarantee in the provision of goods and services and in the buffering against environmental change. As a result, we have been assisting to a growing interest in the identification and definition of policy oriented strategies, ranging from prevention to adaptation measures, so as to deal with such pressures.

In order to guarantee the success of such policies, today, and more than ever, both natural and social scientists focus their attention on the study of ecosystems’ life and functioning. On one hand, natural scientists analyse the conditions for ecosystems’ persistence stressing the relevance of resilience in terms of the capacity of a natural system to maintain its functioning. In other words, resilience is here interpreted as a buffer against environmental changes or disturbances. On the other hand, economists allocate particular effort in exploring a set of tools so as to identify and assess the value of resilience, measured in terms of its impacts on human welfare. In this context, resilience is interpreted as a natural insurance capital against the risk of ecosystems’ malfunctioning, and the consequent damages associated to a potential interruption of the ecosystems’ ability to provide goods and services.

This paper focuses on the analyses and evaluation of resilience anchored in an economic perspective.

The paper is organized as follows. Section 2 introduces the concept of resilience as originally put forward in the ecological literature. Section 3 presents and discusses the motivations to perform economic valuation, in general, and non-market valuation of ecosystems' resilience, in particular. Section 4 defines and explains the concept of economic perspective, which will serve as the platform for the discussion and evaluation of resilience. Section 5 presents an illustration. Section 6 concludes.

2. A natural science perspective on resilience

2.1 Introduction

The concept of resilience has found application in many different fields. In physics, for instance, it identifies the resistance of building materials to collision, by providing an indicator of materials' fragility: a material poorly resilient is more fragile and *vice versa*. In the ecological literature, resilience, firstly defined by the theoretical ecologist Holling (1973), refers to the understanding of ecosystems' dynamics, in general, and its conditions for persistence, in particular (Gunderson, 2000). Abandoning the traditional equilibrium-centred ecological view, which has been focusing on the static analysis of ecosystem's equilibrium, Holling proposes a dynamic approach to the analysis of ecosystem functioning. From Holling's perspective, resilience is then defined as the amount of disturbance that can be absorbed before the system redefines its structure and respective processes without moving the system from the current state to another state. This perspective is referred to in the literature as *ecological resilience* (Holling, 1986; 1996).

Since the pioneering work of Holling, other versions with respect to the concept of resilience have been put forward by natural scientists. Among them, we can find the definition proposed by Pimm (1984). According to Pimm, resilience is identified as the time necessary for a system to return to an equilibrium once the system has been the target of an environmental change or disturbance. The respective amount of time gives an indication of the ecosystem ability to assimilate the change, which is in turn inferred as a measurement of resilience. The faster is the recovery, the minimum is the time to return to equilibrium and therefore the stronger the resilience of the system. This perspective is referred to in the literature as *engineering resilience* (Holling, 1986; 1996).

We can discuss in more detail each approach by exploring the use of Figure 1, as originally proposed by Scheffer *et al*. (1993) and Carpenter *et al*. (1999).

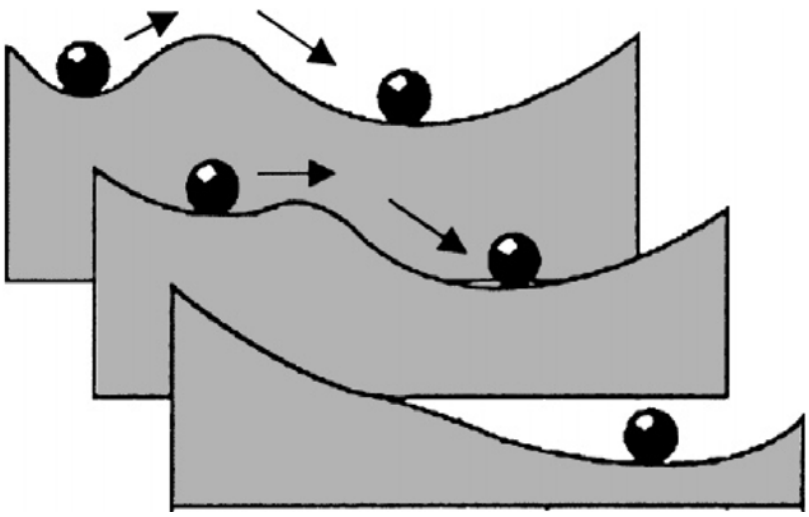

Figure 1 – Ecological and engineering resilience

Source: Scheffer (1993), Carpenter *et al*. (1999).

The ball represented in Figure 1 depicts the system state, the convex set represents the stability domain and the arrows represent the disturbances that the system is subject to. An equilibrium exists whenever the ball lies down, after having experienced other positions induced by disturbances. In this setting, *ecological resilience* can then be defined as the maximum size of the ripples before the ball reach the new equilibrium after perturbations occurred. On the other hand, *engineering resilience* can be thought as the return time of the ball to the initial equilibrium, i.e. to the bottom of the convex set, depending on the slope of the sides of the convex set. In both cases, resilience depends on the shape of the convex set, which is, as shown by the three slices represented in Figure 1, subject to changes. These changes result from the alteration, often human induced, of parameters, such as birth rates, death rates, carrying capacity, migration or per capita predation, governing interactions between ecosystems (Beisner *et al*., 2003).

As recently pointed out by Gunderson (2000), both perspectives, i.e. *ecological resilience* and *engineering resilience*, have in common the fact that both deal with aspects of stability of system equilibrium. In other words, both investigate the persistence of a system, which is supposed to operate near or close to an equilibrium state, concentrating on the self-organized behaviour of that natural system over time. On the contrary, the definitions differ because they offer alternative measures of the capacity of a system to maintain its functioning and stability.

Such differences reflect alternative assumptions about the existence of either single or multiple ecosystem's equilibrium. The *ecological resilience* perspective, which focuses on conditions far from any steady state, where instabilities can flip a system into another stability domain, implicitly assumes the existence of multiple locally stable equilibria and the tolerance of the system to perturbations that facilitate transitions among stable states. The lower the natural system's capacity to adapt to changes, the higher is the risk for the system to shift into a qualitatively different state. When such new state is undesirable, restoring the system to its previous state can be complex, expensive and sometimes it reveals to be impossible. In case of uncertainty and potential irreversibility of the change, the interplay between stabilizing and destabilizing forces is then particularly relevant for the maintenance of ecosystems' functioning. When destabilizing forces are predominant, the natural system could be unable in the new qualitatively state to guarantee to humans the provision of the same goods and benefits as in the previous state. From the ecological resilience perspective, particular attention is then focused on maintaining the existence of ecosystem's functions relevant to human welfare. The *engineering resilience* perspective instead assumes the existence of a global stability, meaning that the behaviour of a system remains within the stable domain containing a single steady state. Then, from this perspective resilience does not impact on which equilibrium the ecosystem will reach, but rather on how it will reach its equilibrium. As a consequence, the main emphasis is put on the efficiency of the path to reach the single best equilibrium steady state. The more resilient the ecosystem, the faster is the process of returning to the original equilibrium state, i.e. the higher is the probability of maintaining the efficiency in ecosystems' functioning. This indirectly implies that the variability of natural systems can be to a certain extent effectively controlled by humans and its consequences are, at least up to a certain point, predictable.

In order to analyse and value resilience, next sub-section will be devoted to the identification, and definition, of resilience relationship with species diversity and natural systems' functioning. In doing so, we will refer to the notion of ecological resilience: ecosystems' complexity and their unknowable and unpredictable evolution over time (Deutsch et al., 2002) seem to be more realistically consistent with the existence of multiple local equilibria.

2.2 Resilience, system functioning and species diversity

Species diversity refers to the variety of species on earth, or in any other given geographical area. Such diversity is associated with a large degree of uncertainty. In fact, estimates of the total number of species on earth range from 5 to 300 million, of which about 1.5 million have been described, and less than 0.5 have been analyzed for potential economic benefit properties

(Miller *et al.* 1985; CBD 2001). The best-catalogued species groups include vertebrates and flowering plants, with other groups, such as lichens, bacteria, fungi and roundworms, relatively under-researched (Wilson 1988a; Pimm *et al.* 1995). A long-standing theoretical paradigm has predicted that species diversity is important because it enhances the productivity and stability of ecosystems (Odum 1950). In this stream of thought, some authors distinguish species according to their impact in ecosystem stability and resilience. In particular, Walker (1992) distinguishes two types of species, *drivers* and *passengers*. *Drivers* correspond to the species that directly, or indirectly, influence the ability of the ecosystem to function, to provide goods and services as well as to buffer against changes or disturbances in the future. *Passengers* correspond to the set of species that do not have a significant role in altering the states of the ecosystem. In this context, while removing *passengers* usually induces little effect in the system performance and absorption capacity, removing *drivers* may cause a large impact, threatening system resilience by reducing its buffer ability to absorb disturbances. The plant *Banksia prionotes* well illustrates the Walker's notion of driver (Walker, 1995). In the wheatbelt in Western Australia, during a certain period of the year this plant is the only source of nectar. The loss of such a species would probably induce the loss of all the honeyeaters of the region and all the plants for which honeyeaters are vectors for pollen. The overall impact of Banksia prionotes loss on plant-species diversity in that area would then be consistent. In other areas, the effect would instead not be so critical. In the coastal regions of Western Australia, for instance, honeyeaters can find alternative sources of nectare in other Banksia species flowering at the same time. As a consequence, there the Banksia prionotes does not identify a driver species: its functional role is easily substitutable by other species.

Some recent studies, however, acknowledge that no pattern, or deterministic relationship needs to exist between species diversity and the stability of ecosystems (Johnson *et al.* 1996). Others instead suggest that the stability of ecosystems, and thus resilience, may be linked to the prevalence of a rather limited number of organisms and groups of organisms that seem to drive or control the critical processes necessary for ecosystem functioning – known as *keystone species* (Paine 1969; Folke *et al.* 1996). The extinction of these species reduces the ecosystem's capacity to accommodate external shocks, like climatic and human influences, and ultimately results in the loss of spatial variety in ecosystem types. Therefore, analyzing keystone species is about determining the minimum range of species within which the different state variables can be disturbed without flipping from the current ecosystem to another regime of behaviour (Perrings and Opschoor, 1994, Holling *et al.* 1995; Reggiani *et al.* 2002, Christianou and Ebenman, 2005).

The ability of an ecosystem to maintain its self-organization and integrity, without undergoing the evolving, and possibly irreversible, change is associated with crossing the thresholds between stability domains. This notion is closely linked to the guarantee of the variety of ecosystem functions (De Leo and Levin 1997, Turner *et al.* 1998). Ecosystem functions, including interconnections between hydrological and geomorphological systems, photosynthesis and food web support, are the result of interactions between its structure and processes. Ecosystem structure refers to the tangible biotic and abiotic items such as plants, animals, soil, air and water of which an ecosystem is composed. Ecosystem processes refer instead to the dynamics of transformation of matter or energy between living and abiotic systems. These processes, in turn, are responsible for the provision of life support services, e.g. resilience benefits, such as assimilation of pollutants, cycling of nutrients, soil generation and preservation, pollination of crops, and maintenance of the balance of gases in the air (Maltby *et al.* 1996a and 1996b). Furthermore, they also enable the development and maintenance of the ecosystem structure that is, in turn, the basis for the continued provision of goods and services.

Natural and human systems coexist and are mutually interrelated. Arrows in Figure 2 show the different interactions existing among them.

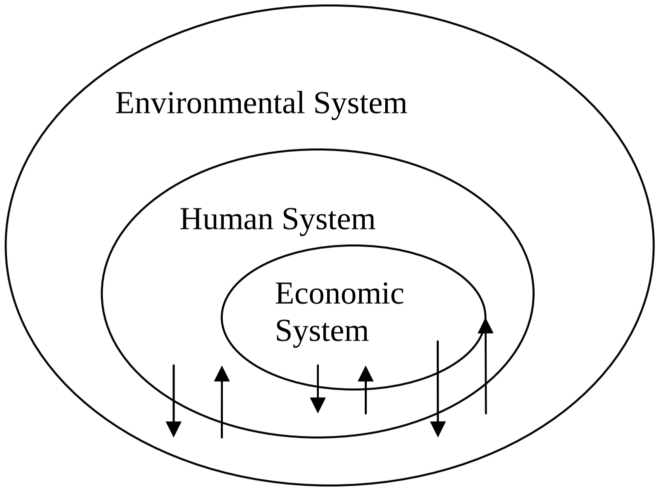

Figure 2 - Linkages between system's resilience and anthropogenic behaviour

Source: *Batabyal et al*. (*2003), adapted.*

As a matter of fact, humans share with other species a fixed amount of natural resources. If economic activities depend on the flow of goods and services provided by ecosystems, ecosystems are in turn dependent on the economy, due to the complexity of the interconnections between human and natural systems. Shocks to the joint economic-environment system (fire, storms or pest outbreaks) can affect both ecological and economic levels. This relationship will be discussed in more detail in the following sub-section.

2.3 Linking system's resilience to anthropogenic behaviour

A dominant element in recent discussions about ecosystem's functioning is the worry about the influence of the human activities in threatening the stability and continuity of ecosystems (Pimm *et al.* 1995; Simon and Wildavsky 1995). In recent years, many economists have focused their attention towards the valuation of the stability and continuity of ecosystems in terms of their ability to guarantee the provision of goods and services to mankind. Stability and continuity of ecosystems, i.e. resilience, today represents, more than ever, a valuable natural resource and requires our attention for two main reasons. First, it provides a wide range of direct and indirect benefits to mankind, which occur on both local and global scales. Such benefits include, *inter alia*, the maintenance of the genetic library, the direct provision of food, watershed protection and waste assimilation (Folke *et al*., 1996). Second, many human activities contribute to general, unprecedented pressures on natural systems and on their capacity to absorb exogenous perturbations without changes, i.e. their resilience. For instance, the accumulation of nutrient concentrations in lakes water until a certain critical threshold is passed usually induces an increase in water turbidity and eutrophication (Deutsch *et al*., 2002). The consequent loss of animals and plants diversity would affect recreation and fishing activities. Similarly, fire and grazing pressures for sheep and cattle production on rangelands produce a shift from grass to the less productive woody plant (small trees and shrubs) dominance (Deutsch *et al*., 2002). Overharvesting of fish stocks, global warming and pollution are instead some of the principal causes of the coral reefs degradation into alternative ecosystem regimes, dominated by macroalgae or sea urchin-barren (Nordemar and Kautsky, 2002).

In particular, humans are responsible for pressures on resilience at both species diversity and ecosystems' functioning levels. At species diversity level, the assumption of a stabilizing role of keystone species implies that systems are more resilient and thus more able to absorb exogenous perturbations without changes. To such thresholds corresponds the focus of many policy actions. The general idea is to respect the existence of extinction thresholds, even if accepting a certain degree of redundancy in the role of the different species. These, in turn, will insure against any unpredictable impacts in terms of ecosystems' deterioration of ecosystems' processes and functioning (Mooney *et al*., 1995). In such a context, the level of human activities can induce ecosystems to cross such thresholds, threatening system's resilience – including the overexploitation of species for commercial use. This is for instance the case, *inter alia,* of Asian and African elephants, rhinoceroses and certain kinds of orchids and cacti, included among species protected by the Convention of International Trade in Endangered Species of Wild Fauna and Flora (OECD, 1997).

At ecosystems' functioning level, disturbances induced by human activities may threaten the ecosystem's ability to provide a wide range of goods and services, including the direct provision of food and the maintenance of the genetic library (Table 1).

Table 1 - Ecosystems' services provided to humans

watershed protection
mitigation of flood and droughts
waste assimilation
detoxification
decomposition
microclimatic stabilization
purification of air and water
generation and renewal of soil and its fertility
pollination of crops and other vegetation
control of agricutltural pests
dispersal of seeds
transport of nutrients
direct provision of food from sea and land
maintenance of the genetic library

Source: Perrings (1999), adapted

For any ecosystem to function, a minimum level of variety of communities of living organisms and their abiotic environments is required. The task of evaluating ecosystem's benefits for humans requires significant information regarding what the ecosystem does, what is worth for resilience and what its impact is to human welfare. The value of ecosystem structure is generally more easily appreciated than that of ecosystem resilience, due to the informational requirements necessary for the second to be known. Assessing ecosystem capacity to guarantee the provision of current nutrient retention and pollution absorption for any given region, for example, is extremely difficult. Such processes cannot in fact be easily observed and controlled by humans, who can only notice some effects of their mulfunctioning. But ecosystem structure is also incompletely known. To assess the value of, for instance, the insect fauna diversity when many of these species have never even been described taxonomically, pushes human knowledge beyond its current limits (Westman 1985). Even if ecology has come to understand ecosystem processes to the extent that some relationships and their implications for humans are now evident, many questions still remain unsolved. However, due to the uncertain and potentially irreversible consequences in terms of ecosystems' functioning and human welfare, the complex interplay between the range of human activities and the natural environment cannot be ignored. In particular, scientists face the important challenge of improving their understanding of the impact of resilience on human welfare: the preservation of ecosystem processes and their consequent good functioning requires in fact the preservation of ecosystem resilience.

3. Motivations for economic valuation

3.1 Introduction

Because we live in a world with scarce resources, one is frequently asked to make the choice regarding the use and management of these resources. In this context, if policy makers decide to invest on the protection of, for example, marine ecosystems integrity by creating a mairne wilderness area, less financial resources would be available for other policy areas, such as national health. In addition, the investment on the protection of marine ecosystems' resilience brings along with it the provision of public values, which are not fully priced on current markets. In other words, marine ecosystems provide a wide range of benefits to humans and most are not valued on market prices. For example, a good functioning of marine ecosystems is able to provide an important role in balancing the local chemical composition of the water and we do not observe a market price that reflects the welfare impact of such benefit. Given that most human activities are priced in one way or other, in some decision contexts, the temptation exists to downplay or ignore marine quality benefits on the basis of non-existence of prices. The simple and simplistic idea here is that a lack of prices is identical to a lack of values. Clearly, this is a slightly biased perspective. Therefore, carrying out proper pricing is one of the main reasons to undertake economic assessment of environmental resources. Three other main reasons can also be identified. These are performing cost-benefit analysis, environmental accounting, and assessing natural resource damage. These will subsequently be considered in more detail.

3.2 Cost-benefit analysis

Cost-benefit analysis (CBA) is a welfare-theoretic method to trade-off the advantageous and disadvantageous effects of a proposed project by measuring them in monetary terms. CBA emerged as an attempt to systematically incorporate economic information that can be applied to project and policy evaluations. Since CBA has traditionally been defined in terms of gains and losses to society, project-oriented CBA has tended to be confined to public sector investment projects. The first evaluation studies were carried out in the USA in the 1950s to deal with ‘intangibles’ in a consistent way, e.g., for river basin projects and infrastructure projects. These methods found much application, *inter alia*, in World Bank practices. They were also heavily criticized for many inherent shortcomings, which has led to many new or adjusted methods, such as cost-effectiveness analysis, goals-achievement methods and multicriteria analysis (see Nijkamp *et al.* 1991).

The use of CBA to evaluate policy is more recent (see for an overview Boardman *et al.* 2000). Like an investment project, policies have costs and benefits. For example, standards for marine pollutants concentrations and taxation of marine pollutants are two different policies, which, in turn, are associated with different gains and losses to society. The basic rule of CBA in decision-making is to approve any potentially worthwhile policy if the benefits of the policy exceed the costs. Moreover, to make the best choice, a decision-maker should opt for the policy option with the greatest positive net present value. Other criteria exist, such as ranking and evaluating projects according to their 'internal rate of value' or according to the 'benefit cost ratio' - see Hanley and Spash (1993) for a literature review on CBA and its application to environmental issues; Lima e Santos (2001) for the evaluation of biodiversity policy.

From an environmental agenda perspective, CBA has been used in the USA for evaluating policies since the late 1970s. However, only after Reagan's Executive Order 12291, in 1981, has CBA been extensively used for evaluating new regulations. In contrast, in Europe there are no legal requirements for CBA for new regulations. An exception is the UK, whose 1995 Environment Act envisions the use of CBA in policymaking. Clearly, the use of and the critical judgments of CBA in public policy is still a matter of ongoing debate among most of the European policy makers.

3.3 Environmental accounting

Various efforts have been made to adjust national accounting systems and associated gross national product (GNP) statistics for the depreciation of environmental assets and for negative externalities such as pollution and the loss of biodiversity. The theoretical literature explores alternative ways of adjusting conventional estimates of national income to reflect environmental deterioration (Aronsson *et al.* 1997). Green (or environmental) accounting is one possible strategy (Lawn, forthcoming).

The underlying idea is to add to the traditional national accounting system information on physical flows and stocks of environmental goods and services – the so-called physical satellite accounts. In the Dutch context, for example, the Netherlands Central Bureau for Statistics developed the NAMEA, a National Accounting Matrix that includes both economic and Environmental Accounts (Keuning and de Haan 1996). An important aim of green accounting is to obtain an adjusted ‘green’ GNP. This can play a potentially crucial role in policymaking since the GNP has a powerful influence on macro-economic policy, financial markets and international institutions (OECD, IMF, and World Bank). If national income is wrongly estimated, then economic analysis and policy formulation are based on the wrong premises, thus ‘steering’ the society by the wrong compass (Hueting 1980; El Serafy 1999). Adjustment of the national accounts to reflect ecosystem quality loss will lower the GNP (Gerlagh *et al.* 2002). Nevertheless, practice shows that the adjustment of national accounting systems is not an easy task. It is therefore necessary to achieve international agreement about harmonizing GNP adjustments, allowing for the comparison of GNP and national accounts between countries. Independent of which valuation methods are used for this purpose, it is clear that monetary valuation of the depreciation of environmental assets and negative externalities, such as pollution and the loss of biodiversity, is a key element in green environmental accounting.

3.4 Natural resource damage assessment and legal claims

Natural resource damage assessments (NRDAs) appraise how much society values the destruction of natural resources. An important benchmark in the history of NRDA is the massive oil spill due to the grounding of the oil tanker Exxon Valdez in Prince William Sound, in the northern part of the Gulf of Alaska, on March 24, 1989. This was the largest oil spill from a tanker in USA history. More than 1,300 km of coastline were affected and almost

23,000 birds were killed (Carson *et al.* 1992). After the oil spill, the State of Alaska commissioned a legal action in order to assess Exxon's financial liability in the damage to the natural resources. A national contingent valuation study estimated the loss to USA citizens as a result of the oil spill. The natural resource damage resulting from the Exxon Valdez oil spill was estimated at $2.8 billion. For the first time, a governmental decision expressed the legitimacy of nonuse values as a component of the total damage value. To date, NRDAs are only undertaken in the USA and have not yet become an issue in the European policy agenda because of different legal arrangements between member states. The recent sunk of the tanker Prestige in front of the Galician coast is at this aim very significant.

Such sunk caused in November 2002 probably the largest oil spill to date, with about 60.000 tons of heavy fuel oil leaked into the sea and affecting more than a thousand of coastline (Cajaraville *et al*., 2005). The Spanish Ministry of Science and Technology launched in 2003 two special actions, one of which aimed to monitor the health of sentinel coastal organisms and the other focused on determining the effects of the oil spill on the platform ecosystems and fisheries resources. The second action included also the analysis of the socioeconomic effects of the oil spill: the Economy of Fisheries Resources group of the University of the Basque Country was charged of assessing the losses in the fish-extraction, commercial and transformation sectors in Basque Country. The evaluation of the losses focused on some socioeconomic variables of interest for the whole sea-industry complex, including income and employment levels, but no NRDAs were undertaken.

4. Resilience as a source of economic value

4.1 Introduction

As we have seen, the concept of resilience has been put forward in the field of natural sciences. In their study, economists are concerned with the magnitude of disturbance that can be absorbed before an ecosystem is displaced from one state to another. In other words, with the ability of an ecosystem to maintain its self-organization without undergoing the destructive and possibly irreversible change involved in crossing the threshold between stability domains (Pearce *et al*., 1989; Deutsch *et al*., 2002). The maintenance of the system self-organization is interpreted in terms of the ecosystem's stability and integrity of the platform that, in turn, is responsible for the provision of a wide range of direct and indirect benefits affecting human welfare. In short, from the economic perspective, the relevance of resilience is mainly due to its role in guaranteeing the provision of a wide range of benefits, including the ecosystem absorption capacity of external perturbations. Resilience represents a valuable natural resource in particular today, in a worldwide context characterized by general, unprecedented human pressures on the natural environment and the consequent increasing threats to ecosystems' stability and integrity.

One can question why, if resilience generates so many benefits for humans it has been ignored for a long while from the policy agenda and it is still ignored today when, more than ever, we assist to unprecedented pressures on ecosystem stability. When answering to this question, it is current practice to distinguish between 'proximate' and 'fundamental' factors that underpin the ecosystem's ability to buffer against disturbances. While the proximate factors relate to the worldwide trend of human population growth, and its impact on production and consumption patterns, the fundamental causes are associated with the conditions within which system's resilience decisions are made. Two important fundamental causes emerge (Nunes *et al*., 2003). The first relates to market failures and the second to the lack of property rights. Many resilience benefits, such as the ability to maintain the genetic library, are not 'cashed' flows, i.e., there is no market price mechanism that fully captures such benefits. In other words, markets fail to internalize protection benefits. For this reason, these are known in the economic literature as positive external effects (or externalities), i.e., positive unintended effects outside the market on the welfare or productivity of other individuals. In such a context, the individual rate of return on conservation will almost certainly fail to compete with the individual rate of return on development projects. This is a consequence of the individual utility maximizing behaviour, ignoring the existence of positive externalities. According to the usual economic analysis, the optimal individual choice corresponds in fact to a preservation of resilience below the level that would be socially optimal, because the external effects are not included within the individual rational calculation. The second fundamental cause is related to the lack of property rights. The unrestricted depletion of ecosystem resilience due to the lack of enforceable property rights causes negative externalities to society, because there is no owner able to privately capture resilience benefits. This identifies an example of what is usually called, since the seminal work of Hardin (1968), 'the tragedy of the commons'. In a context in which individuals are supposed to be rational, the personal calculation of utility would induce every one to compare his share of the cost of decreasing resilience to his share of the cost of preserving resilience. Since for each individual the first one is less than the second one due to the absence of property rights, the result will be a loss of ecosystems' resilience greater than the socially optimal level. In particular, population growth makes today the problem of properly defining property rights even more relevant. At worldwide level, this problem emerges also because of the high importance of the spatial element arising from a reciprocal relationship: (1) local, anthropogenic rooted processes have global impacts in terms of system's resilience; and (2) global trends in system's resilience give rise to local effects. For example, natural habitats have been historically converted to agricultural use. Such process has heavily affected ecosystems' functioning and structure and, by reducing ecosystems' resilience, has impacted on geochemical cycles and thus contributed to the global warming we are now experiencing on hearth. The global climate change, in turn, is having local consequences in terms of soil erosion, downstream sedimentation, flooding and salinization.

4.2 Resilience as a source of welfare

As already stressed, natural and human systems are strongly interlinked. Demographic, social, cultural and economic trends have many impacts on the functioning of such systems. A reduction in the systems' resilience makes them more vulnerable to external perturbations, which otherwise would have been absorbed without structural change (Folke *et al*., 1996). An emblematic example of loss of resilience is represented by the construction of the Aswan dam that, by ending the annual floods of the Nile river, has impoverished the Egyptian agriculture and induced a great portion of the rural population to migrate into Cairo. This in turn was responsible for additional welfare damages in terms of urban poverty and unemployment (Batabyal *et al*., 2003). Another significant example is captured in the mid-western regions of the United States of America. There, the loss of flood protection services provided by upstream wetlands as a consequence of land use decisions has played a key role in the intensive flooding of Mississippi river and its tributaries (Batabyal *et al*., 2003).

The reduction of systems' resilience, measured by an overcoming of ecological thresholds, causes discontinuities in the provision of ecological service flows, and a negative impact on human welfare. This situation configures a challenge for the economic theory because of the uncertainty of the thresholds' levels values and the magnitude of the change (Muradian, 2001). In the case of the greenhouse gas emissions, for example, marginal increases in carbon dioxide emissions lead to marginal increases in global temperature, but when a critical threshold is crossed the consequent massive warming can induce important destabilizing phenomena, such as *El Nino* and *La Nina* events (Batabyal *et al*., 2003).

In case of irreversible damages or slowly reversible changes, welfare costs derived from the reduction of system's resilience are imposed on both present and future generations (Perrings and Stern, 1999). Irreversibility, in fact, typically occurs when the ecosystem original state, and the consequent flow of goods and services to humans, can be restored only at excessive costs to society, either in terms of resources allocation or of time required (Van Kooten and Bulte, 2000). In both cases, the welfare costs associated to irreversible environmental damages are not easy to quantify. From one hand, it is not always possible for scientists to *ex ante* assess their amount, due to the limited knowledge on the type and duration of the complex natural phenomenon involved. From the other hand, uncertainty also derives from the lack of knowledge on the preferences of future generations: different welfare priorities could imply different environmental concerns. In this context, resilience can then be interpreted in terms of *natural insurance capital* (Prakash and Pearce 1993; Barbier *et al*., 1994; Folke *et al*., 1996; Deutsch *et al*., 2002). Therefore, any decrease in the level of uncertainty is characterized and measured in terms of an increase in the supply of insurance against potential transformation of natural capital. Such an insurance effect is stronger the weaker is the substitutability between environmental capital and human-made capital (e.g. technology). Resilience, at least for some forms of environmental capital with limited substitutability, represents then a *critical* capital (Prakash and Pearce, 1993), captured in terms of both environmental functions for the human system (ecosystem goods and services) and environmental functions for the natural system (life-support functions) (Deutsch et al., 2002). The loss of resilience, by altering essential ecosystems' functions and processes, modifies in fact the risk associated with a given set of environmental conditions and induces a different value of potential productivity, in terms of goods and services flows (Brock *et al*., 2000). The task is now to evaluate the benefits of ecosystem's resilience for human welfare.

However, before we need to present and discuss the underlying characteristics that the economic valuation perspective relies upon.

4.3 Economic valuation perspective

The valuation of any scarce resource, such as ecosystems' resilience, relies on cultural, political and religious determinants. As proposed by van Ierland *et al*. (1998), the perspectives on value range according to the underlying human attitudes with respect to natural environment. For the sake of illustration, we here take into account two opposite perspectives, the eco-centric value perspective well know in the literature as *deep ecologist* and the anthropocentric *techno-economic dominance* (Table 2).

Table 2 - A classification of attitudes towards nature

Attitudes	*Principles*
Deep Ecologist	Only biodiversity issues matter
Ecological Approach	Recognition of economic needs
Stewardship	Protect biodiversity, allow economic activity
Multifunctional Use	Biodiversity and economic activity
Economic Attitude	Priority to economic activity
Techno-economic Dominance	Only economic issues matter

Source: van Ierland et al. (1998), adapted)

According to the *deep ecologist* value perspective, top priority is given to the conservation of the environment, in general, and protection of resilience, in particular, independently of their importance in terms of their role in the human economic activities. The underlying idea of this biotic, egualitarianism anchored perspective, is that nature is characterized by intrinsic values (Ehrenfeld 1988). On the contrary, the *techno-economic dominance* value perspective, assumes a rather optimistic view with respect to the self-regulation capacity of the environment and accepts depletion in natural resources to reach economic growth targets, without recognizing any intrinsic right for protection. In between, the other attitudes (*ecological approach*, *stewardship*, *multifunctional use*, *economic attitude*) differ each other because of a decreasing relevance attributed to the environment and an increasing relevance attributed to economic activities.

The present paper explores an economic perspective with respect to the valuation of ecosystem resilience. For the relevance recognized to the preservation of the environment and to the practice of economic activities, this economic perspective is placed between the above mentioned multifunctional use and economic attitude. In particular, following the framework proposed by Nunes and van den Bergh (2001), such perspective is based on an *anthropocentric* point of view on value. This means that the concept of value has its foundations in individual welfare. The basic premise of economic valuation, and thus economic value of a resource, is the effect of the supply of the same resource on the well-being of the individuals who make up the society. Therefore, if society wishes to make the most in terms of individuals' well-being maximisation, the issue of the assessment of the total economic value of resilience benefits is a key issue in terms of policy decisions. Implicitly, this also means that the economic perspective on resilience value embraces an *instrumental* approach. This makes explicit the fact that resilience benefits are used for instrumental purposes, either in terms of production opportunities or in terms of consumption opportunities (Fromm 2000).

Many people, however, do not feel comfortable with placing an instrumental value on natural resources, in general, and resilience, in particular. The common argument is that the resource has a value on its own – also known as 'intrinsic value'. A more extreme version of this argument claims that instrumental monetary valuation is a nonsense exercise (Ehrenfeld 1988). This approach is not embraced here. On the contrary, the *instrumental* approach is based on the idea that making public or private decisions, which affect system's resilience, implicitly means attaching a value to it, which is disclosed in terms of different changes in the level of resilience benefits associated to each scenario or policy options. In other words, humans have preferences with respect to different states of the world and their environmental quality characteristics, and value changes (rather than levels) of environmental quality characteristics (including system's resilience), which are relevant for their welfare.

Furthermore, the economic perspective on the valuation of ecosystem resilience is a monetary valuation. Monetary indicators serve as means and not as ends in valuation. In short, economists make the use of monetary indicators as common units for the comparison and ranking of alternative resilience scenarios or policy options. The magnitude of the monetary indicator translates the value of the resilience benefits in human welfare, in terms either of the individual production or consumption opportunities. Since monetary valuation reflect individual preferences and all individuals are invited to participate in the valuation, it can be said to be rooted in a democratic approach allowing direct comparisons with alternative options in order to make public decisions, including those affecting ecosystem's resilience.

Finally, the economic valuation is anchored in a *reductionist* perspective and for this reason is based on the idea that one is able to disentangle, or disaggregate, the total value of resilience benefits into different economic value categories, notably direct use and passive use or nonuse values (Pearce and Moran 1994), reflecting the different human motivations (*bottom up approach*, Nunes and van den Bergh, 2001). Next section will focuses on these different economic value categories.

4.4 A possible classification of resilience's value components

Bearing in mind the proposed economic valuation approach, the different value categories of resilience can be identified and described by referring to a simple conceptual framework as shown in Figure 3.

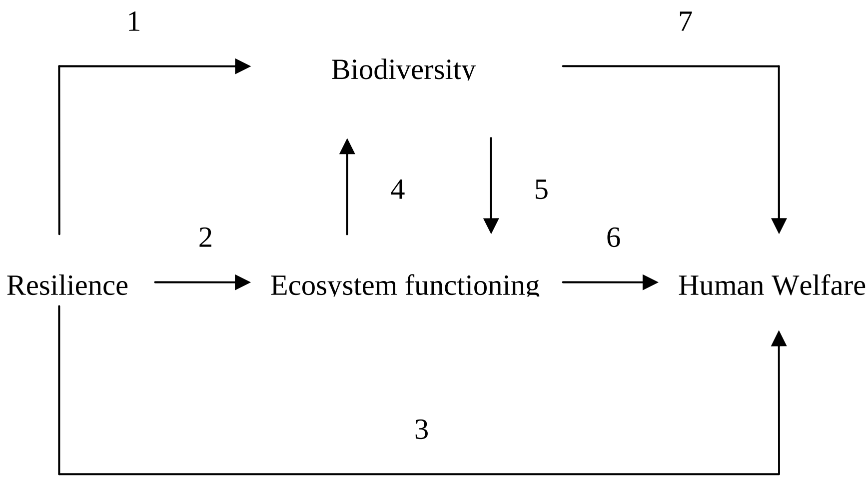

Figure 3 - Resilience's value components

A first value category of resilience is denoted by link 1-7. This captures the benefits humans derive from the maintenance of ecosystem stability, expressed in terms of the intertemporal provision of goods and services. This resilience value component is referred to as *direct use value* and captures both the value of the information pool contained in plants and animals (including genetic diversity) as well as the value of the supply of a variety of landscapes, habitats and respective biotic communities (including ecosystem diversity). As far as the impacts of resilience on gene diversity are concerned, one can proceed in assessing this value component in terms of its added value as an input in the provision of market priced goods (such as new medicines or pharmaceutical products). Alternatively, the impacts of resilience on ecosystem diversity can be inferred by individual demand on natural habitats, including experience and recreational values.

A second value category of resilience is captured by link 2-6. This denotes the benefits accruing to humans by ecosystem functioning, expressed in terms of its ability to buffer against disturbances. This resilience value component is referred to as *indirect use value.* This value component includes the welfare that humans derive from preventing any malfunctioning in the ecosystem and thus avoiding any interruption in the provision of environmental and ecological services, such as flood control, groundwater recharge, nutrient removal, toxic retention and CO_2 sequestration.

Another value category of resilience is captured by link 3. This denotes the benefits accruing to humans from ecosystem stability, and its impact in terms of the guarantee in the intertemporal provision of goods and services, and ecosystem integrity, expressed in terms of its impact in guaranteeing the intertemporal ability to buffer against disturbances, even if none of the both are directly consumed or experienced by the individual. In other words, it simply corresponds to individual knowledge that these resilience benefits exist, independently of their human use. In general terms, these reflect moral and philanthropic considerations, including intra and inter generations altruistic motives. For this reason, link 3 denotes a *passive* or *non-use* value component of resilience.

In addition, we have a value category captured by link 4-5. This depicts the feedbacks that human experience and knowledge of resilience benefits cause on ecosystem stability and integrity. In other words, this value category is interpreted as an insurance against potential damages caused by the feedback of the wide range of human activities on ecosystem stability and integrity. For this reason, link 4-5 denotes a *option* value component of resilience. Next sub-section will focus on the analysis of this value component of resilience, by looking in particular at its policy implications in terms of natural disaster prevention and management.

4.5 The option value component of resilience: policy implications

As previously stressed, resilience derives part of its economic value (option value component) from its role in protecting against potential damages due to a loss of ecosystem stability and integrity. From this point of view, resilience corresponds to a measure of ecosystems' *vulnerability* to damage, defined as the probability that ecosystems are affected by a certain risk factor (Cardona, 2003). As such, resilience identifies a key element in risk and natural disaster prevention and management. In fact, a reduced vulnerability implies a reduction in risk and consequently in the probability of future natural disasters. Then, the analysis of the main issues on risk assessment from the perspective of disaster risk may help in defining the option value component of resilience.

Following Cardona (2003) and Freeman *et al*. (2003), it is possible to divide the different components of disaster risk management into two phases. Actions required in the pre-disaster phase include risk identification, risk reduction and risk transfer, while the post-disaster phase is primarily devoted to disaster management actions. *Risk identification* deals with hazard assessment, monitoring and forecasting, as well as with vulnerability and risk assessment. *Risk reduction* refers instead to preventive and mitigation policy measures, aimed to intervene on the causal factors of the negative event. *Risk transfer* includes insurance and financial protection through specific instruments, such as national or local calamity funds, catastrophe bonds, public services with safety regulation (energy, water and transportation). Once the negative event occurred, *disaster management* identifies response and recovery actions devoted to humanitarian assistance, damage assessment, rehabilitation and reconstruction of damaged infrastructure, revitalization of affected sectors.

Within this framework, resilience plays a significant role during the pre-disaster phase as insurance against the uncertain and potentially irreversible effects of ecosystem malfunctioning, i.e. as factor reducing risk. In particular, resilience acts as factor reducing the expected total damage related to the negative event, at both prevention and mitigation level. As such, its option value component can be, therefore, approximated by two different components. From one hand, by the costs of implementing *prevention* policy measures, i.e. policies aimed to reduce the probability of disaster. From the other hand, by the costs of implementing *mitigation* policy measures, i.e. policies aimed to ex ante reduce the economic losses due to the eventual occurrence of natural disasters or extreme events.

As recognized by the recent literature on disaster prevention and management (Rose, 2004), the system's capacity to absorb the feedback of the wide range of human activities on ecosystem stability and integrity deals in particular with three main elements. These are: *reduced failure probability*, *reduced consequences from failure* and *reduced time to recovery*. The first element depends on how a community intervenes to reduce the probability of structural or system failure, for example by implementing public policies aimed to preserve system's resilience through limitations on agricultural practices near river basins. The second element results instead from ex ante protective measures aimed to minimize the negative effects due to structural or system failure, such as protective barriers in case of periodical flooding. Finally, the last element refers to how quickly the system returns to normality in case of external shocks.

The following sub-section will discuss an illustration on the economic value measurement of resilience benefits in terms of natural insurance against high water events in the city of Venice. Such benefits will be expressed in terms of the avoided welfare costs , which would be associated to the negative event of high water in case of low Lagoon system resilience. At this aim, the analysis will focus on welfare costs derived by business interruption. Even if among the welfare costs associated to natural disasters particular emphasis has traditionally been devoted to the measure of property damage, also the other category of measurement is recently receiving significant attention (Perrings, 1995; Rose, 2004; Carraro *et al*., 2004). Then, the social value of maintaining the Venice Lagoon resilience will be approximated with the value of the forgone output from the human activities normally carried out in such ecosystem and interrupted because the disaster occurred.

5. The Venice Lagoon case study

5.1 Periodical flooding as a signal of ecosystem's resilience loss

The Venice Lagoon configures a particular type of ecosystem, in which natural and anthropogenic dynamics coexist, being strongly interlinked to one each other: complex global transformation processes (e.g. climate change, see level rising) add up to strong local human pressures (e.g. water pollution, solid waste).

Natural, historical and cultural specificities makes the area of great interest for an economic analysis, in particular due to the effects of the growing anthropogenic pressures inducing dynamic disequilibria. A typical example of these disequilibria is the more and more recurrent phenomenon of *acqua alta*, i.e. the periodical high water event causing (partial) flooding of the historical centre of Venice. Venetians have learnt to coexist and deal with this sort of periodical event since the very beginning of the history of the city, by adapting their own behaviour to tackle with this problem. Nevertheless, during the last decades the city has experienced a systematic increase in the intensity of the phenomenon, as confirmed by the upwards trend of mean tidal excursions in Venice. Figure 4 depicts the average water level trend from 1993 to 2001.

The high water impacts on architectural, artistic and cultural heritage and the economic damages to the population and its visitors are of increasing concern to both Venetians and policy makers (Ministero dei lavori pubblici, 1997). The factors influencing such a pattern include, *inter alia*, the increase of the Adriatic sea level of about 23 cm during the twentieth century. This is due to both natural and human causes, among which particularly relevant are the subsidence of the islands of Venice and the global climate change phenomenon. Nevertheless, the increasing intensity and frequency of the high water event can be considered a signal of low resilience of the Lagoon ecosystem as a whole (Ministero dell'Ambiente, 1998).

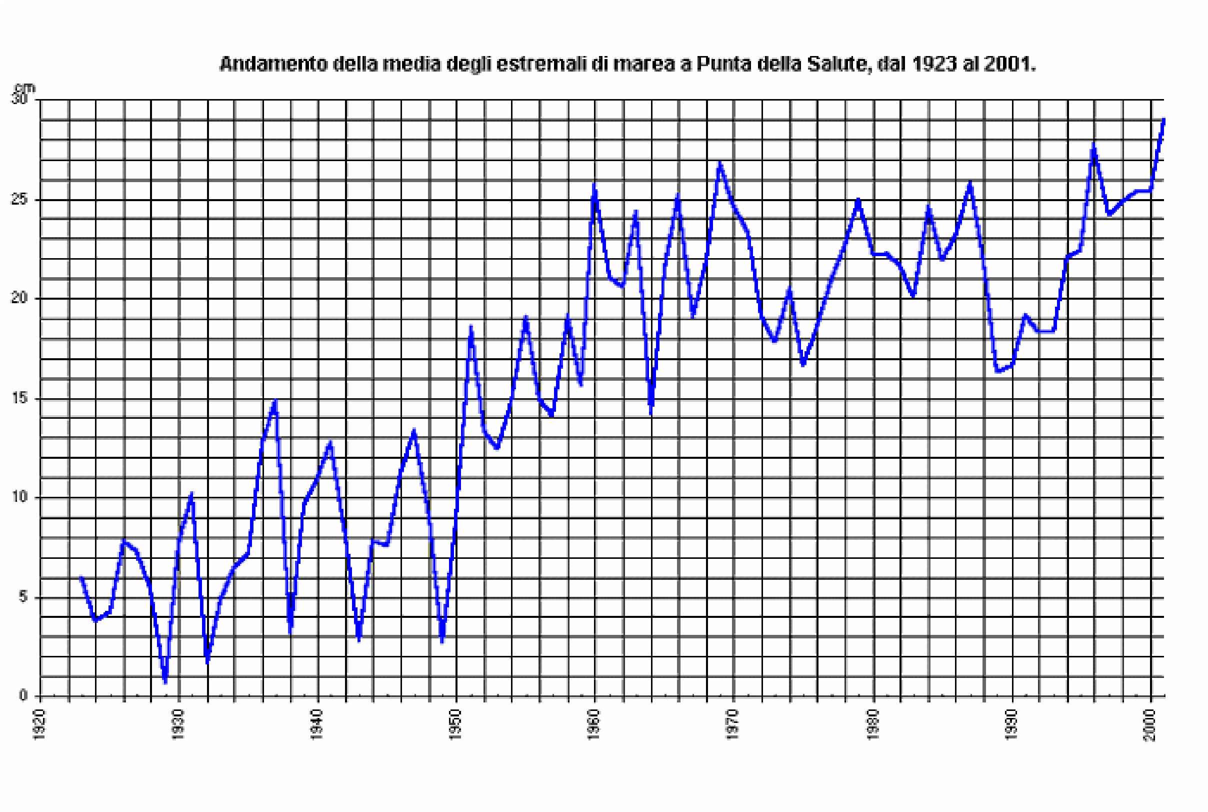

Figure 4 – Intertemporal series of mean tidal in Venice

Source: www.comune.venezia.it/maree/dal1867.asp

Most of the existing valuation studies analysing the economic impacts of high water events in the Lagoon refer to the introduction of the mobile-gates project called MOSE (*Modulo Sperimentale Elettromeccanico*) and usually quantify structural damages according to physical, non-monetary approaches.

In a recent valuation report, Carraro and Nunes (2004) propose instead a monetary assessment of the economic short-term impacts of high water events on all registered business activities located and operating in ground floors units in the city of Venice. A short-term perspective means that the attention is focused only on the consequences of high water events for the business activities already in place, without extending the analysis also to the potential variation in the composition and number of such activities. Impacts are viewed as a sum of *on site damages* and *off site damages*. The first damage category refers to damages on the structures and materials due to the infiltration of water. The second damage category instead captures the damages attributable to the reduced overall functioning of the city dynamics during high water events. In particular, this category of damages is related to the uncertainty with respect to the future revenues of business activities and for this same reason impacts on the economic value of such activities.

Bearing in mind such a categorizing of acqua alta damages, the economic valuation of the first damage category can be approximated by the costs connected to the implementation of mitigation policy measures. These measures are aimed to minimize the damages high water and salinity cause to building elements through the adoption of high water protection measures and equipment, such as hydraulic pump, the rising of pavements and *paratia* (a system of mobile barriers protecting doors that give access to street). The costs related to mitigation policy measures then reflect a *private insurance* perspective, since they capture the value of the direct damages caused by high water on the architectonical structure and equipment (e.g., inner and front door maintenance, cleaning of pavements and maintenance of walls), which are financially supported by the privately owned business activities.

The economic valuation of off site damages is instead related to the costs of reducing the likelihood of flooding events through the implementation of prevention policy measures. Such measures typically cannot be undertaken by private individuals, but has to be the result of concerted actions at regional, national or international scale. In fact, the off site damage component refers to a set of high water impacts that are not routinely traded in regular marketplaces. These include *inter alia* the impact of the high water, and respective uncertainty of the city dynamics' performance, on the economic value of the business activities. As a consequence, the economic valuation of off site damages is relevant from a *public protection* perspective.

5.2 Empirical valuation of on site damages

The empirical valuation is focused on the estimation of both on site and off site economic damages induced by the high water event. The estimation exercise referred to the first damage component is based on two COSES surveys (1999 and 2001). In order to proceed with the monetary assessment of damages, the high water events considered in the empirical exercise include the valuation of two possible high water events: single exceptional events; weakly periodical flooding episodes and general high water scenarios. In particular, three different scenarios are taken into account in addition to the current situation ('business as usual' scenario), which reflects the historical annual average frequencies of high water events registered by the Venetian Municipality during the period 1996-2001. The second scenario ('Defence 110') corresponds to the situation in which collective defensive measures are taken against all events above 110 cm. The third scenario ('Climate change') considers an average sea-level rise of 10 cm induced by climate change events. Finally, the last scenario is a combination of the 'Defence 100' and 'Climate change' scenarios.

This part of the valuation exercise combines an integrated dose-response modelling with an expert-based valuation approach, relative to maintenance and repair activities due to high water and related market prices: it assesses the physical damage on structures and materials and estimates the economic value of the damage without retrieving people's preferences.

The estimation results, referred to the considered different scenarios, are shown in Tables 3. As can be noticed, the total on site economic damages range on average between 4,4 and 2,4 millions of euro. In particular, if the climate change hypothesis is assumed, the estimated increase of on site damages is around the 43% with respect to current situation. The introduction of a public protection project induces a reduction in the estimated total on-site economic damages equal to the 27% with respect to current situation. When the climate change hypothesis is assumed, the estimations reduction due to the public protection project is instead equal to the 40%.

This resulting estimates provide just a partial proxy for the total on site damages, because they do not include the economic value of impacts on furniture, working hours and commodities. As such, they only partially capture the economic value of the privately implemented mitigation policy measures.

The second part of the valuation exercise is based on a survey instrument portrayed in terms of conjoint valuation method (Carraro and Nunes, 2004), since the monetary valuation of off site economic damages refers to a damage component not fully captured by market prices. This type of survey based valuation methodology, applied to a CORILA questionnaire (2003), is characterized by the use of a specific econometric model, which is anchored in the random utility micro-economic framework, exploring the direct impact of different high water levels on the choice of the business activities. Respondents choose between alternative scenarios according to respective impact in terms of welfare gain/loss. Bearing in mind the respondent's choices, it is possible to infer such impact in monetary terms, reporting this magnitude as a proxy of the economic value of the business activity. The aim is, *inter alia*, to quantify the negative impacts of high water in terms of its limiting public access and usability of the city and its business activity.

This specific methodology has been conceived so as to: 1) identify a set of characteristics that together with the effects of high water influence the economic value of a business activity located at ground level in the city of Venice; 2) employ a valuation tool that links the economic value of a business activity with a consumer choice model and 3) estimate the impact of the different characteristics under consideration in the individual choices, thereby inferring the respective valuation mechanisms in monetary terms.

Table 3- On-site economic damages

	BAU	*Climate Change*	*Public protection project + 110 cm*	*Public protection project + 110 cm and climate change scenario*
Cost category				
Substitution of inner doors				
Higher Bound	1441144	2233543	460253	460253
Lower Bound	893049	1638794	402604	460253
Maintenance of front doors				
Higher Bound	135281	284389	108467	124133
Lower Bound	63598	164415	63598	122566
Maintenance and cleaning of pavements				
Higher Bound	78797	188408	42151	100401
Lower Bound	68519	163833	36653	87305
Maintenance of walls				
Higher Bound	2920301	3232043	2773044	3019921
Lower Bound	1240247	156812	1106891	1380724
Total on-site economic damages				
Higher Bound	4575522	5938383	3383916	3704709
Lower Bound	2265413	3535853	1609746	2050849

Source: Breil et al. (2005), adapted

Bearing in mind this economic valuation framework, a bid valuation function for alternative sets of business locations is estimated, assessing the marginal impact of the different characteristics under consideration. In particular, one business activity is modelled and described with respect to the following three different characteristics: the position of the business activity with respect to the sea level; whether the shop is accessible by means of a catwalk; whether the shop is located in an area mainly visited by tourists.

Table 4 - Estimation results

on site damages per year	2,4 - 4,4 millions Euro
costs due to an exceptional event (16 november 2002)	10,6 millions Euro
on site costs of a year similar to 2002 (including protection measures)	30 millions Euro
total on site and off site damages per year (CORILA questionnaire)	22 millions Euro

Source: Carraro et al.(2004)

All the estimation results are summarized in Table 4. The monetary assessment of damages induced by an exceptional flooding event, such as the extraordinary flooding of 16^{th} November 2002, is estimated at 10.6 million of Euro, while the economic value of damages of a year similar to 2002 is estimated at 30 million of Euro. The total economic value of damages due to high water event for an entire year are estimated at 22 million of Euro.

6. Conclusions

This paper has focused on the analysis of ecosystems' resilience as scarce environmental resource. The attention has been directed on resilience value from an economic perspective, exploring the motivations for economic valuation and its relevance in terms of human welfare. In this context, resilience has been interpreted as a natural insurance capital against the risk of ecosystems' malfunctioning and the consequent damages associated to a potential interruption of the ecosystems' ability to provide goods and services to humans. From the analysis emerged two main important messages.

The first message is of a methodological nature and refers to the review of the main reasons that steer economists to be interested in studying resilience, as the concept has been originally developed in the field of natural sciences. The economic perspective has been put forward in order to shed light on the basic premises that anchor the economic valuation of any scarce resource, such as resilience and its benefits. It has been argued that policy guidance constitutes an important motivation for pursuing economic valuation of resilience since respective monetary estimate is crucial when performing a cost-benefit analysis, natural resource damage assessment or green environmental accounting. Moreover, given that most of the human activities are priced in a way or another and most of ecosystem's stability and integrity benefits are not market priced, one can be tempted to downplay or ignore resilience benefits on the basis of non-existence prices. The simple and simplistic idea here is that a lack of prices, basically induced by market failures (externalities and public goodness) and the lack of enforceable property rights, is identical to a lack of values. Clearly, this is a slightly biased perspective. The need for carrying out proper pricing is instead one of the main reason to undertake economic assessment of environmental resources, such as resilience. In this context, we developed a simple framework to identify and describe the different value components, related to resilience, which economists need to assess when performing an economic valuation exercise.

The second message emerges from the empirical exercise briefly discussed at the end of the paper. Such exercise refers to the economic assessment of damages induced by high water events in the city of Venice. The increasing frequency and intensity of flooding, causing many serious damages to business activities carried out at ground level, can be interpreted as a signal of a decreasing resilience in the Lagoon natural system. Bearing in mind such a premise, the analysis has focused on the interpretation of the estimation results in terms of the economic value of the Lagoon resilience. In doing so, we referred to both, a private insurance perspective and a public policy perspective. From the first perspective, the economic value individuals attribute to resilience because of its contribution to the reduction of the negative impacts of flooding on business activities can be approximated by the prevention and mitigation costs necessary to minimize the welfare losses. In particular, such costs correspond to the amount individuals are willing to pay for ex ante limiting the damages caused by flooding on business activities. From the public policy perspective, the estimate of the off-site damages reflect the uncertainty with respect to the future revenues of the business activities. Taken together, the estimated on site and off site damages can be considered as a proxy of the option value component of the total economic value of the Lagoon system's resilience. In fact, by assuming that the higher frequency of flooding is a signal of a progressive loss of resilience in the Lagoon, then the higher the resilience, the lower the frequency and intensity of high water events (resilience as natural insurance capital). Investing in measures to minimize the welfare losses due to flooding on business activities (i.e. paying for mitigation and remediation costs) can be thought as an insurance premium against the economic damages induced by high water, i.e. the costs to reduce the risk of negative consequences related to this event. In other words, for individuals working in the business activities located at the ground floor of some Venetian buildings the costs of reducing the economic damages of flooding can be thought as a proxy of the economic value of the possibility to maintain as much as possible constant business output flows in the future. Such costs represent then the amount individuals are willing to pay to both reduce impacts from ecosystem failure (high water events) and reduce time to recovery from the negative consequences of the failure.

References

Aronsson, T., P.-O. Johansson and K.-G. Lofgren (1997), Welfare Measurement, Sustainability and 'Green' Accounting - a Growth Theoretical Approach, Edward Elgar, Cheltenham, UK and Lyme, USA.

Barbier E.B., Burgess J. and Folke C. (1994), Paradise Lost? The Ecological Economics of Biodiversity, Earthscan Publications Limited, London.

Batabyal A.A., Kahn J.R. and O'Neill R.V. (2003), "On the Scarcity Value of Ecosystem Services", Journal of Environmental Economics and Management, 46, 334-352.

Beisner, B.E., Haydon, D.T. and K. Cuddington (2003), Frontiers of Ecological Environment, 1 (7), 376-382.

Boardman, A., Greenberg, D., Vining, A. and D. Weimer (2000), Cost Benefit Analyis: Concepts and Practice, 2nd Edition, Prentice Hall.

Bosello, F., Buchner, B. and Carraro, C. (2003), "Equity, Development and Climate Change Control", Journal of the European Economic Association, Vol. 1, 2-3, pp. 601-611.

Breil M., Gambarelli G. and Nunes P.A.L.D. (2005), Economics valuation of on-site material damages of high water on economic activities based in the city of Venice: results from a dose-response-expert-based valuation approach, in Fletcher C.A. and Spencer T. (eds.), Flooding and Environmental Challenges for Venice and its Lagoon: State of Knowledge, Cambridge University Press, Cambridge.

Brock W.A., Maler K.-G and Perrings C.A. (2000), Resilience and Sustainability: The Economic Analysis of Non-Linear Dynamic Systems, Discussion Paper n. 133, The Beijer International Institute of Ecological Economics.

Cajaraville M.P., I. Diez, J.M. Gorostiaga, N. Etxebarria, I. Astorkiza, J.V. Tarazona and G. Diez (2005), Integrated assessment of the effects of the Prestige oil spill in Galizia and the Biscay Gulf: toxicological, ecological, productive and socioeconomical aspects

(Prestepse), VERTIMAR-2005, SYMPOSIUM for monitoring of Accidental Oil Spill Projects in Marine Environment related with VEM2003 Program of Ministry of Education and Science (Spain).

Cardona, O.D. (2003), 'The Need for Rethinking the Concepts of Vulnerability and Risk from a Holistic Perspective: A Necessary Review and Criticism for Effective Risk Management', in G. Bankoff, G. Frerks and D. Hilhorst (eds.), Mapping the Vulnerability: Disasters, Development and People, Earthscan Publishers, London, UK.

Carpenter S.R. and Cottingham K.L. (1997), "Resileince and Restoration of Lakes", Conservation Ecology, 1.

Carraro C. and P.A.L.D. Nunes (2004), Valutazione economica degli impatti di breve periodo del fenomeno delle acque alte sulle attività economiche della città di Venezia, Rapporto Finale, Comune di Venezia, CORILA.

Carson, R. T., R. C. Mitchell, W. M. Hanemann, R. J. Kopp, S. Presser and P. A. Ruud (1992), "A Contingent Valuation Study of Lost Passive Use Values Resulting from the Exxon Valdez Oil Spill", Report prepared for the Attorney General of the State of Alaska, Washington, USA.

CBD - Convention on Biological Diversity (2001) *Biodiversity Global Outlook*, www.biodiv.org.

Christianou, M. and Ebenman, B. (2005), "Keystone species and vulnerable species in ecological communities: strong or weak interactors?", Journal of Theoretical Biology, 235, Issue 1 (July), 95-103.

De Leo, G. A., and S. Levin (1997), "The multifaceted aspects of ecosystem integrity", Conservation Ecology, 1(1), 3.

Deutsch L., Folke C. and Skanberg K. (2002), The Critical Natural Capital of Ecosystem Performance as Insurance for Human Well-Being, Discussion Paper n. 156, The Beijer International Institute of Ecological Economics.

Ehrenfeld, D. (1988), Why Put A Value In Biodiversity, in E.O. Wilson (Ed), Biodiversity, National Academy Press, London, UK.

El Serafy, S. (1999), Steering the Right Compass: Proper Measurements for Sound Macro-economic Management, paper presented at International Symposium Valuation of Nature and Environment, Royal Netherlands Academy of Arts and Sciences, Amsterdam, The Netherlands.

Folke, C., C.S. Holling, C. Perrings (1996), “Biological Diversity, Ecosystems and the Human Scale”, Ecological Applications, 6, No. 4, 1018-1024.

Freeman, P.K., L.A. Martin, J. Linnerooth-Bayer, R. Mechler, G. Pflug, K. Warner (2003), Disaster Risk Management, National Systems for the Comprehensive Management of Disaster Risk and Financial Strategies for Natural Disaster Reconstruction, Inter-American Development Bank, Sustainable Development Department, Environment Division, Integration and Regional Programs Department, Regional Policy Dialogue, Washington D.C., USA.

Fromm, O. (2000) “Ecological Structure and Functions of Biodiversity as Elements of Its Total Economic Value”, Environmental and Resource Economics, 16, 303–28.

Gerlagh, R., R. Dellink, M. Hofkes and H. Verbruggen (2002), “A Mesure of Sustainable Development for the Netherlands”, Ecological Economics, 41, 157–74.

Gibson, C.C., E. Ostrom and T.K. Ahn (2000), “The Concept Of Scale And The Human Dimensions Of Global Change: A Survey”, Ecological Economics, 32, 217–39.

Gunderson, L.H. (2000), “Ecological resilience – in theory and application”, Annual Review of Ecological Systems, 31, 425-39.

Hanley, N. and C.L. Spash (1993), Cost-Benefit Analysis and the Environment, Edward Elgar, Aldershot, UK and Brookfield, USA.

Hardin, G. (1968), 'The Tragedy of the Commons', Science, 162, pp. 1243-48.

Hueting, R. (1980), New Scarcity and Economic Growth, North-Holland, Amsterdam, The Netherlands.

Holling, C.S. (1973), "Resilience and stability of ecological systems", Annual Review of Ecological Systems, 4, 1-23.

Holling, C.S., D.W. Schindler, B.W Walker and J. Roughgarden (1995), "Biodiversity in the Functioning of ecosystems: an Ecological Synthesis", in Perrings, Ch., (eds.), Biodiversity Loss. Economic and Ecological Issues, Cambridge University Press, Cambridge.

Holling, C.S. (1996), "Engineering resilience vs ecological resilience", in Schulze P.C. (ed.), Engineering within Ecological Constraints, National Academy Press, Washington DC.

Keuning, S.T. and M. de Haan (1996), What is a NAMEA?, Statistics Netherlands National Accounts Paper, Voorburg, The Netherlands.

Johnson, K.H, K.A. Vogt, H.J. Clark, O.J. Schmitz and D.J. Vogt (1996) 'Biodiversity And The Productivity And Stability Of Ecosystems', Trends in Ecology and Evolution, 11, 372–77.

Lambeck, R.J. (1992), 'The role of faunal diversity in ecosystem function', in R.J Hobbs (ed.), Biodiversity of Mediterranean ecosystems in Australia, Surrey Beatty & sons, Melbourne.

Lawn, P. (ed.), Sustainable Development Indicators in Ecological Economics, Edward Elgar Publishing Ltd, Camberley, UK, forthcoming.

Lima e Santos, J.M. (2001), 'Evaluating multidimensional biodiversity policy: what can we learn from contingent valuation studies of biological resources in the context of rural amenities?', in OECD, Valuation of Biodiversity Benefits. Selected Studies, Paris, France.

Maltby, E., D.V. Hogan and R.J. McInnes (Eds) (1996a), Functional Analysis of European Wetland Ecosystems, Final Book - Phase One, EC DGXII STEP Project CT90-0084, Wetland Ecosystems Research Group, University of London, UK.

Maltby, E., D.V. Hogan and R.J. McInnes (Eds) (1996b), The functioning of River Marginal Wetlands-Improving the Science-base for the Development of Procedures of Functional Analysis, Commission of the European Communities, DG XII, Environment and Waste Recycling, Water Pollution Research Book Series.

Miller, K. R., J. Furtado, C. Klemm, J.A. McNeely, N. Myres, M.E. Soule and M.C. Texton (1985), Maintaining Biological Diversity, The Key Factor for a Sustainable Sociaty, JUCN, Gland, Switzerland.

Ministero dei Lavori Pubblici, Magistrato delle Acque, Nuovi interventi per la salvaguardia di Venezia, Interventi alle bocche lagunari per la regolazione dei flussi di marea, Studio di impatto ambientale del progetto di massima, Allegato 3, Studi socio-economici: parte B, 1997.

Ministero dell'Ambiente, Valutazione di impatto ambientale relativa al progetto: Interventi alle bocche lagunari per la regolazione dei flussi di marea, Studio di impatto ambientale del progetto di massima, Parere di compatibilità ambientale della Commissione per le Valutazioni di Impatto ambientale, 1998.

Mooney, H.A., Lubchenco, J., Dirzo, R. and Sala, O.E. (1995), Biodiversity and Ecosystem Functioning: Basic Principles, in Heywood V.H. (ed.), Global Biodiversity Assessment, UNEP, Cambridge University Press, Cambridge.

Muradian, R. (2001), "Ecological thresholds: a survey", Ecological Economics, 38, 7-24.

Nijkamp, P., P. Rietveld and H. Voogd (1991), Multicriteria Evaluation in Physical Planning, North-Holland, Amsterdam, The Netherlands.

Nunes, P.A.L.D. and J.C.J.M. van den Bergh (2001), Economic Valuation of Biodiversity: Sense or Nonsense, Ecological Economics, 39, pp. 203-222.

Nunes, P.A.L.D., J.C.J.M. van den Bergh and P. Nijkamp (2003), The Ecological Economics of Biodiversity. Methods and Policy Applications, Edward Elgar, Cheltenham.

Odum, H.T. (1950) ‘Bird Populations Of The Highlands Plateau In Relation To Plant Succession And Avian Invasion’, Ecology, 31, pp. 587–605.

OECD (1997), Experience with the use of trade measures in the convention of international trade in engendered species of wild fauna and flora (Cites), Paris, France.

Paine, R.T. (1969), The *Pisaster-Tegula* interaction: prey patches, predator food preference, and intertidal community structure, Ecology, 50, 950-961.

Pearce, D., A. Markandya and E.B. Barbier (1989), Blueprint for a Green Economy, Earthscan Publications Ltd, London.

Perrings, C. and H. Opschoor (1994), “The Loss of Biological Diversity: Some Policy Implications”, in Turner K. et al. (eds.), Ecosystems and Nature, Edward Elgar, London.

Perrings, C. and Walker B. (1997), Biodiversity, resilience and the control of ecological-economic systems: the case of fire-driven rangelands, Ecological Economics, 22, 73-83.

Perrings, C. (1998), “Resilience in the Dynamics of Economy-Environment Systems”, Environmental and Resource Economics, 11, 3-4, 503-520.

Perrings, C. and D.I. Stern (1999), “Modelling Loss of Resilience in Agroecosystems: Rangelands in Botswana”, Environmental and Resource Economics, 16, 185-200.

Pimm, S.L (1984), “The complexity and stability of ecosystems”, Nature, 307, 321-326.

Pimm, S., G. Russell, J. Gittleman and T. Brooks (1995), ‘The Future of Biodiversity’, Science, 269, 347–50.

Prakash, T.N.R. and D. Pearce (1993), Sustainability as resilience: measuring sustainable development, unpublished.

Reggiani, A., de Graaf and P. Nijkamp (2002) ‘Resilience: An Evolutionary Approach to Spatial Economic Systems’, Networks and Spatial Economics, 2, pp. 211–29.

Rose, A. (2004), “Defining and measuring economic resilience to disasters”, Disaster Prevention and Management, 13, No. 4, 307-314.

Scheffer M., Hosper S.H., Meijer M.L. and Moss B. (1993), „Alternative Equilibira in Shallow Lakes“, Trends Evol. Ecol., 8, 275-79.

Simon, H. and A. Wildavsky (1995), ‘Species Revisited’, in J. Simon (Ed) The State of Humanity, Blackwell, Oxford, UK.

Turner, R.K., J.C.J.M. van den Bergh, A. Barendregt and E. Maltby (1998) ‘Ecological-Economic Analysis of Wetlands: Science and Social Science Integration’, in T. Söderquist (Ed) Wetlands: Landscape and Institutional Perspectives, Beijer Occasional Paper Series, Beijer International Institute of Ecological Economics, Stockholm, Sweden.

Van Ierland E.C., de Kruijf H.A.M. and van der Heide C.M (1998)., Attitudes and the Value of Biodiversity, A paper on biodiversity valuation & statements by participants of Benin, Bhutan, Costa Rica and The Netherlands at the workshop ?Biodiversity Valuation in Cultural Context’, March 2-7, San Josè, Costa Rica.

Van Kooten, G.C. and Bulte, E.H. (2000), The economics of nature. Managing biological assets, Blackwell Publishers, Malden.

Walker, B.H. (1992), “Biological diversity and ecological redundancy”, Conservation Biology, 6, 18-23.

Walker, B.H. (1995), ‘Conserving Biological Diversity through Ecosystem Resilience’, Conservation Biology, 9 (4), pp. 747-52.

Westman, R.E. (1985), Ecology, Impact Assessment and Environmental Planning, Wiley, Chichester, UK.

Wilson, E.O. (Ed) (1988a) *Biodiversity*, National Academy Press, London, UK.

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:

http://www.feem.it/Feem/Pub/Publications/WPapers/default.html
http://www.ssrn.com/link/feem.html
http://www.repec.org
http://agecon.lib.umn.edu

NOTE DI LAVORO PUBLISHED IN 2006

SIEV	1.2006	*Anna ALBERINI:* Determinants and Effects on Property Values of Participation in Voluntary Cleanup Programs: The Case of Colorado
CCMP	2.2006	*Valentina BOSETTI, Carlo CARRARO and Marzio GALEOTTI*: Stabilisation Targets, Technical Change and the Macroeconomic Costs of Climate Change Control
CCMP	3.2006	*Roberto ROSON*: Introducing Imperfect Competition in CGE Models: Technical Aspects and Implications
KTHC	4.2006	*Sergio VERGALLI*: The Role of Community in Migration Dynamics
SIEV	5.2006	*Fabio GRAZI, Jeroen C.J.M. van den BERGH and Piet RIETVELD*: Modeling Spatial Sustainability: Spatial Welfare Economics versus Ecological Footprint
CCMP	6.2006	*Olivier DESCHENES and Michael GREENSTONE*: The Economic Impacts of Climate Change: Evidence from Agricultural Profits and Random Fluctuations in Weather
PRCG	7.2006	*Michele MORETTO and Paola VALBONESE*: Firm Regulation and Profit-Sharing: A Real Option Approach
SIEV	8.2006	*Anna ALBERINI and Aline CHIABAI*: Discount Rates in Risk v. Money and Money v. Money Tradeoffs
CTN	9.2006	*Jon X. EGUIA*: United We Vote
CTN	10.2006	*Shao CHIN SUNG and Dinko DIMITRO*: A Taxonomy of Myopic Stability Concepts for Hedonic Games
NRM	11.2006	*Fabio CERINA* (lxxviii): Tourism Specialization and Sustainability: A Long-Run Policy Analysis
NRM	12.2006	*Valentina BOSETTI, Mariaester CASSINELLI and Alessandro LANZA* (lxxviii): Benchmarking in Tourism Destination, Keeping in Mind the Sustainable Paradigm
CCMP	13.2006	*Jens HORBACH*: Determinants of Environmental Innovation – New Evidence from German Panel Data Sources
KTHC	14.2006	*Fabio SABATINI*: Social Capital, Public Spending and the Quality of Economic Development: The Case of Italy
KTHC	15.2006	*Fabio SABATINI*: The Empirics of Social Capital and Economic Development: A Critical Perspective
CSRM	16.2006	*Giuseppe DI VITA*: Corruption, Exogenous Changes in Incentives and Deterrence
CCMP	17.2006	*Rob B. DELLINK and Marjan W. HOFKES*: The Timing of National Greenhouse Gas Emission Reductions in the Presence of Other Environmental Policies
IEM	18.2006	*Philippe QUIRION*: Distributional Impacts of Energy-Efficiency Certificates Vs. Taxes and Standards
CTN	19.2006	*Somdeb LAHIRI*: A Weak Bargaining Set for Contract Choice Problems
CCMP	20.2006	*Massimiliano MAZZANTI and Roberto ZOBOLI*: Examining the Factors Influencing Environmental Innovations
SIEV	21.2006	*Y. Hossein FARZIN and Ken-ICHI AKAO*: Non-pecuniary Work Incentive and Labor Supply
CCMP	22.2006	*Marzio GALEOTTI, Matteo MANERA and Alessandro LANZA*: On the Robustness of Robustness Checks of the Environmental Kuznets Curve
NRM	23.2006	*Y. Hossein FARZIN and Ken-ICHI AKAO*: When is it Optimal to Exhaust a Resource in a Finite Time?
NRM	24.2006	*Y. Hossein FARZIN and Ken-ICHI AKAO*: Non-pecuniary Value of Employment and Natural Resource Extinction
SIEV	25.2006	*Lucia VERGANO and Paulo A.L.D. NUNES:* Analysis and Evaluation of Ecosystem Resilience: An Economic Perspective

(lxxviii) This paper was presented at the Second International Conference on "Tourism and Sustainable Economic Development - Macro and Micro Economic Issues" jointly organised by CRENoS (Università di Cagliari and Sassari, Italy) and Fondazione Eni Enrico Mattei, Italy, and supported by the World Bank, Chia, Italy, 16-17 September 2005.

	2006 SERIES
CCMP	*Climate Change Modelling and Policy* (Editor: Marzio Galeotti)
SIEV	*Sustainability Indicators and Environmental Valuation* (Editor: Anna Alberini)
NRM	*Natural Resources Management* (Editor: Carlo Giupponi)
KTHC	*Knowledge, Technology, Human Capital* (Editor: Gianmarco Ottaviano)
IEM	*International Energy Markets* (Editor: Anil Markandya)
CSRM	*Corporate Social Responsibility and Sustainable Management* (Editor: Sabina Ratti)
PRCG	*Privatisation Regulation Corporate Governance* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)
CTN	*Coalition Theory Network*