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From no whinge scenarios to viability tree

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Abstract

Avoiding whinges from various and potentially conflicting stakeholders is a major challenge for sustainable development and for the identification of sustainability scenarios or policies for biodiversity and ecosystem services. It turns out that independently complying with whinge thresholds and constraints of these stakeholders is not sufficient because dynamic ecological-economic interactions and uncertainties occur. Thus more demanding no whinge standards are needed. In this paper, we first argue that these new boundaries can be endogenously exhibited with the mathematical concepts of viability kernel and viable controls. Second, it is shown how these no whinge kernels have components, such as harvesting of resources, that should remain within a safe corridor while some other components, in particular biodiversity, have only lower conservation limits. Thus, using radar charts, we show how this no whinge kernels can take the shape of a tree that we name viability tree. These trees of viability capture the idea that the unbounded renewal potential of biodiversity combined with a bounded use of the different ecosystem services are crucial ingredients for the sustainability of socio-ecosystems and the design of no whinge policies reconciling the different stakeholders involved.

Keywords: Minimal whinge, safe operating space, scenarios, ecological economics, modeling, sustainability, viability kernel.

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The need for no-whinge spaces

Achieving the 'Millennium Development Goals' (United Nations, 2012) and operationalizing a sustainable development reconciling human well-being, food security, economic performance, the production of ecosystem services with biodiversity conservation and limited pollution is among the greatest challenges of the century, especially in the face of global changes including climate change and the world demographic transition (Godfray *et al.*, 2010). The creations of the IPCC and IPBES (International Panel for Biodiversity and Ecosystem Services) at the interface between decision support and scientific knowledge are in direct line with these concerns. In that respect, the production and assessment of model-based scenarios and policies such as those examined in Leadley *et al.* (2010) constitute major scientific challenges.

Regarding biodiversity management, the heterogeneity of stakeholders contributes to the complexity in the evaluation and design of public decision making policies, management and scenarios (Doyen *et al.*, 2013). Stakeholders including fishers, farmers, hunters, conservation and regulation agencies, consumers, tourists or NGO's can indeed differ in their interpretations of the world, preferences, strategies, levels of information and inputs in the dynamics of systems. In this context, what may be more readily available to regulating agencies and decision makers is information about what is acceptable / non-acceptable to the various stakeholders. In other words, a realistic goal for management may often be to avoid undesirable states that lead to non-compliance or rejection from stakeholders. Such a goal function has been called the minimum sustainable whinge (MSW) in Pope (1983). Interestingly the word 'sustainable' is used in MSW because piecemeal management measures to silence short term complaints (for example, about subsidy) may lead to worse long term complaints. This MSW can be illustrated for fisheries with objectives of current yield, profit, employment and biodiversity conservation where:

- Profits are seen as the difference between revenues derived from fishing and cost of efforts (days at sea) and are required to remain non negative or above current values. Stakeholders interested in such a goal are mainly producers (fisherfolks).
- Employment concerns local people involved in processing and trading sectors, as well as the local politicians and decision makers.
- Catches are required to stay above the volumes required for food security. Stakeholders concerned here are typically consumers.
- Biodiversity metrics are required to be not too altered. Related stakeholders include environmental NGOs and conservation agencies.

To meet the challenge of sustainable development, Rockstrom *et al.* (2009) also proposed a framework based on boundaries that define the safe operating space (SOS) for humanity, associated with the planet's biophysical subsystems or processes. The framework relies on the idea that most environmental systems react in a nonlinear, often abrupt, way, and are particularly sensitive around tipping levels of certain key variables. If these thresholds are crossed, then these systems could shift into a deleterious state or collapse with disastrous consequences for humans. By contrast, as long as the thresholds are not crossed, humanity has the freedom to pursue long-term social and economic development [1]. Similarly the concept of Safe Minimum Standards (SMS) as in Ciriacy-Wantrup (1952) relates to tipping thresholds and risky areas. Such a geometrical approach has also strong connections with the so-called Goldilocks zone used in astro-physics as in Powell (1996) where the emphasis is put on feasibility through acceptability windows in a dynamic context instead of optimality or stationarity. Tolerable Windows Approach (TWA) as introduced in Petschel-Held *et al.* (1999) also relies on safe boundaries and feasibility regions for the assessment of climate policies.

[1] At this stage, it may be worth distinguishing between global and local/regional systems or scales. The existence of thresholds or tipping points, so that there is a desirable domain of the system and an undesirable one, is most obvious and well evidenced for a number of small-scale, local systems. At the global scale, it is a hypothesis that Planet Earth exhibits this kind of threshold-behavior, but evidence is much weaker. Insofar as we rather address local systems here, e.g. fisheries, we are on the scientifically safe side when using such arguments.

We here first argue that the MSW, SOS, SMS, TWA or Goldilocks, all constitute instances of a relevant approach to ecosystem and biodiversity management for sustainability, if they also account for the interactions between ecological and economic systems. In particular, Rockstrom *et al.* (2009) define a SOS for humanity. Yet, the way how humanity moves in this operating space is to a large extent determined by policymakers and economic leaders in industrialized countries. To transform the concepts of MSW, SOS, SMS, TWA or Goldilocks into a relevant and comprehensive approach for the sustainable management of ecosystem and biodiversity, boundaries related to human needs have to be included as well. For instance, food security and poverty lines combined with demographic, economic growth and technological progress must be considered when designing policies for sustainable development and the management of socio-ecosystems. This is the idea underlying the 'Oxfam doughnut' (Raworth, 2012), with an explicit focus on the social justice requirements underpinning sustainability used at more local or regional scale (Dearing *et al.*, 2014). Moreover, interactions and feedbacks between ecological and economic systems, which often are non-linear, need to be taken into account.

We thus propose to rely on ecological economic approaches, modeling, dynamics and constraints to operationalize sustainable development and MSW. In particular, we argue that the use of viability kernels (Aubin, 1990; Béné et al., 2001; Baumgartner & Quaas, 2009; Schuhbauer & Sumaila, 2016) makes possible the delineation of 'no whinge spaces' for sustainable management, policies and scenarios of ecological-economic systems.

Ecological-economic constraints and interdependencies

In order to sustainably manage ecosystems, an ecological-economic viewpoint bringing together ecological considerations and human well-being is needed. The underlying public policies must be part of a general prospect of sustainable development, reconciling environmental, economic and social requirements with a perspective of equity within and between generations. Bio-economics or ecological economics can contribute to such an objective (Clark, 1990; Costanza *et al.*, 1997; Doyen *et al.*, 2013). The aim of these disciplines is basically to investigate the control of the environmental-economic systems at play by analyzing and designing decision strategies, policies and scenarios for biodiversity together with the commodities, provisioning services and other ecosystem services it provides.

Bio-economic boundaries and whinge thresholds are tightly coupled and concentrating effort on any one of them in isolation is not sufficient because its dynamics is likely to affect the others. If one constraint is violated, then other boundaries are also under serious risk. For instance, significant land-use changes in developing countries influence water resource and local consumption relying on land-use such as farming. The climate-change boundary of SOS depends on staying on the safe side of the freshwater, land, aerosol, nitrogen-phosphorus, ocean and stratospheric thresholds. Not complying with the nitrogen-phosphorus constraint can affect negatively some marine ecosystems, potentially reducing their capacity to absorb CO2 and thus altering the climate boundary but also their ability to provide food. In other words, there is a need to draw on a more integrated, systemic and holistic approach to cope with these ecological-economic constraints and dynamics and to anticipate whinges related to the violation of bio-economic boundaries due to interrelated dynamic processes and feedbacks in the joint ecological-economic system. Uncertainties underlying ecological-economic system dynamics exacerbates and complexifies such a challenge.

Viability kernels

Viability modeling is now recognized by a growing number of scientists and stakeholders as a relevant framework for sustainability and the management of ecological-economic risks and vulnerabilities (Jennings, 2005; Cury *et al.*, 2005; Thébaud *et al.*, 2013; Krawczyk *et al.*, 2013; Schuhbauer & Sumaila, 2016; Doyen *et al.*, 2017; Oubraham & Zaccour, 2018). In the context of dynamic systems, the aim of the viability approach is to explore states and controls that ensure the 'good health' and safety of the system (Béné et al., 2001) over time. By identifying the viability conditions that allow various constraints to be satisfied throughout time, considering both present and future states of a dynamic system, the viability approach conveys information on sustainability and especially strong sustainability (Baumgartner & Quaas, 2009). It accounts for dynamic complexities, uncertainties, risks and multiple sustainability objectives. In that sense, links with the MSW, TWA and SOS are very strong. The approach has already been successfully applied to socio-ecosystem management in several contexts including land-use issues (Mouysset *et al.*, 2014), biodiversity valuation (Béné & Doyen, 2008) or fisheries management (Maynou, 2014; Gourguet *et al.*, 2016; Schuhbauer & Sumaila, 2016; Doyen *et al.*, 2017). In relation to food security, Hardy *et al.* (2013) or Cissé *et al.* (2015) provide useful bio-economic insights in the context of developing countries under strong demographic pressure.

The viability kernel provides a solid and rigorous mathematical tool to address viability issues (De Lara & Doyen, 2008). In short, viability kernels are 'spaces' (states of the socio-ecosystem) from which starts at least one policy trajectory satisfying the whole set of constraints throughout time. The viability kernel is both a conceptual tool to represent sustainability and a computing tool for the applications relying on dynamic programming methods. The viability kernel gives major insights into MSW as illustrated by Figure 1. In that very stylized and simplified bio-economic example inspired by hunting or fishing, a renewable resource is harvested to provide food security. Assume that the initial whinge constraints are lower bounds such as biodiversity minimal level $x_{\lim}$ and guaranteed consumption $c_{\lim}$. Viability kernel as displayed in blue in the right-hand side of Figure 1 is characterized by an upper boundary related to harvesting quotas (the upper curve of the viability kernel) and a more demanding resource ceiling x_{pa} larger[2] than the initial conservation threshold $x_{\lim}$. This is explained in more mathematical terms in the the Box A.

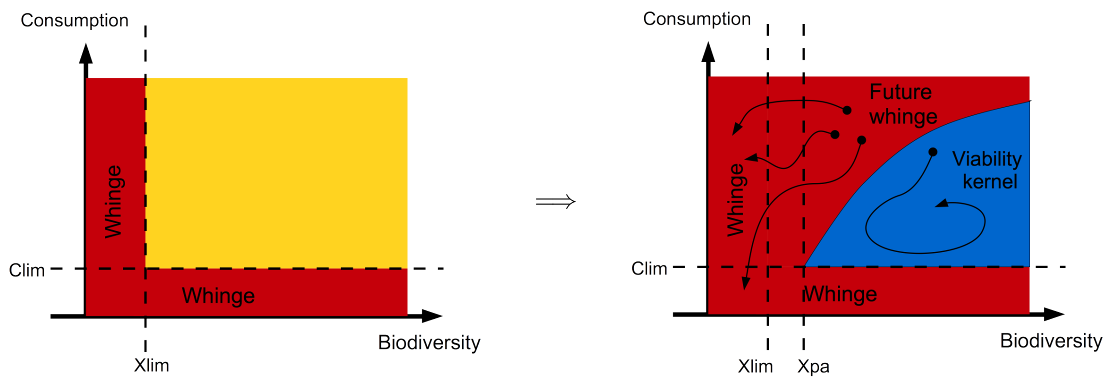

Figure 1: Bio-economic whinge and viability kernel. Left-hand side: In red, the whinge space: In the present case, (for sake of simplicity) we only represent two constraints: the ecological and food security ones (the economic constraint is omitted). These constraints are indicated on the diagram by the two dotted lines and the associated two thresholds: $x_{\lim}$ and $c_{\lim}$. Below these two thresholds the constraints are violated, the system is in crisis and whinges occur. In yellow, viability occurs in a static way. Right-hand side: In blue the viability kernel represents the set of initial conditions of the system which ensures that the controlled dynamics (illustrated by the system trajectories) will satisfy the viability constraints at any time. Above the viability kernel boundary, initial conditions are viable at $t = 0$ but the dynamics of the system is such that future crisis and whinges can not be avoided. Only within the viability kernel is the system without whinge and will remain so at any time in the future.

[2]The notation pa has links with the precautionary limits (B_{pa}) of the ICES approach for fisheries.

Box A: A stylized bio-economic model

A controlled dynamic system under constraints. We consider a simple controlled dynamic system under constraints including the following ingredients:

- A non linear population dynamics with harvest in discrete time: a stock (biomass, abundance of a species) $x(t)$ evolves according to renewable mechanisms f (typically Verlhust growth) and catches $c(t)$

$$x(t+1) = f\big(x(t)\big) - c(t), \qquad t = 0, 1, \ldots \tag{1}$$

  The control of the system is the catch $c(t)$ while $x(t)$ stands for the state of the system.

- A first no whinge constraint relates to ecological conservation with a safe stock threshold:

$$x(t) \geq x_{\text{LIM}}, \qquad t = 0, 1, \ldots \tag{2}$$

- A second no whinge constraint relates to food security with a basic need threshold:

$$c(t) \geq c_{\text{LIM}}, \qquad t = 0, 1, \ldots \tag{3}$$

Viability kernel or no whinge kernel. A more demanding space is provided by the following set of states from starts at least one harvest trajectory $c(.)$ avoiding whinge situations over time in the sense of constraints (2), (3):

$$\text{Viab} = \left\{ x_0 \;\middle|\; \begin{array}{l} \exists\ c(t) \text{ and } x(t) \text{ starting from } x_0 \\ \text{satisfying dynamics (1) and constraints (2), (3) } \forall t \in \mathbb{N} \end{array} \right\}$$

Two contrasted cases. Assume that the population dynamics f satisfies the following conditions: $f_x > 0$; $f(0) = 0$; $f(K) = K$; $f_{xx} < 0$. We can distinguish between two contrasted configurations for the viability kernel as follows.

- **No viability:** the viability kernel is empty: $\text{Viab} = \emptyset$ if the basic need c_{LIM} is too demanding in the sense that $c_{\text{LIM}} > c_{\text{MSY}}$ where c_{MSY} is the Maximum Sustainable Yield defined by

$$c_{\text{MSY}} = \max_{x \geq 0} f(x) - x$$

- **Partial viability:** the viability kernel is nonempty when the basic need c_{LIM} is not too demanding in the sense that $0 \leq c_{\text{LIM}} \leq \text{MSY}$. In that case the viability kernel reads $\text{Viab} = [x_{\mathsf{pa}}, +\infty[$ where the precautionary stock threshold x_{pa} is defined by

$$x_{\mathsf{pa}} = \min\Big(x,\ x \geq c_{\text{LIM}},\ x \geq x_{\text{LIM}}\ f(x) - c_{\text{LIM}} = x\Big)$$

No whinge catches. As proved in De Lara & Doyen (2008), determining viable controls consists in maintaining the state x within the viability kernel Viab. For the previous model, this corresponds to the constraint

$$f(x) - c \geq x_{\mathsf{pa}}.$$

Consequently, viable catches lie within the corridor

$$[c_{\text{LIM}}, c_{\mathsf{pa}}(x)]$$

where the precautionary quota $c_{\mathsf{pa}}(x)$ is defined by $c_{\mathsf{pa}}(x) = f(x) - f(x_{\mathsf{pa}}) + c_{\text{LIM}}$. Flexibility and adaptiveness emerges from this set of viable controls as several no-whinge options can be selected among the interval $[c_{\text{LIM}}, c_{\mathsf{pa}}(x)]$.

Minimal whinge kernel: from a mine pit to a tree of viability

More generally, considering any social-ecological system impacted by several anthropogenic pressures and lower tolerable boundaries on both the states and controls of these socio-ecosystems, we conjecture that the viability kernels look like in Figure 2. Such an outcome expands the stylized bio-economic model associated with Figure 1. The mathematical model underpinning such a figure is portrayed in Box B. This geometric shape of kernels is suggested by different applied modeling works as in (Mouysset *et al.*, 2014; Gourguet *et al.*, 2016; Hardy *et al.*, 2013; Cissé *et al.*, 2015). We termed such domains no whinge kernels for several reasons. First, they are based on feasibility boundaries in line with MSW principle. Second, we called them kernels because they relate to the computation of viability kernels. On the left hand side of the figure 2, the yellow zone depicts combinations of states, controls and indicators remaining above several whinge thresholds including food security, guaranteed profitability or conservation of biodiversity and other ecosystem services (typically cultural or regulating). This zone can also be termed the no whinge space. The consistency between these whinge constraints and the dynamics at play restricts the no whinge domain to the blue area where upper bounds emerge as in Figure 1. This zone related to the viability kernel can also be termed the no whinge kernel because it exemplifies the need for anticipating and avoiding whinge crisis. The shape of a 'tree of life' which emerges is well aligned with the objectives of sustainability scenarios and policies for biodiversity and ecosystem services. This is why we name them viability trees.

Interestingly, the general MSW shape identified for these spaces can be decomposed in three distinct areas. A first zone in red shaped here as a circle[3] exemplifies the need to remain above boundaries to avoid ecological-economic whinges. Such a 'pit mine' indeed captures crisis situations where at least one bio-economic requirement, including basic protein needs or minimal wetlands or forests, or necessary biodiversity is violated. But as said previously, it is not enough to stay above the unsustainable (red) pit to remain safe over time since upper boundaries are needed as upper limits for consumption of renewable resources illustrated in Figure 1. In that case, the TWA metaphor strongly applies. By contrast, the other branch without upper limits and related to biodiversity illustrates the fact that some states do not need to be bounded from both side in the context of sustainable development. Examples of such a result are biodiversity levels from the ecological side which can potentially rise without altering the system sustainability as a whole. To go further, the unbounded potential of biodiversity state captures the idea that the renewable nature underlying biodiversity is a pivotal element of sustainability of the whole socio-ecosystem by providing renewable resources, services, welfare and well-being over time. Such a configuration stresses a significant difference with the planetary space approach, the Oxfam doughnut or TWA where upper limits and ceilings are major elements. In contrast our no whinge kernels and viability trees make possible more open spaces and more room for manoeuvre.

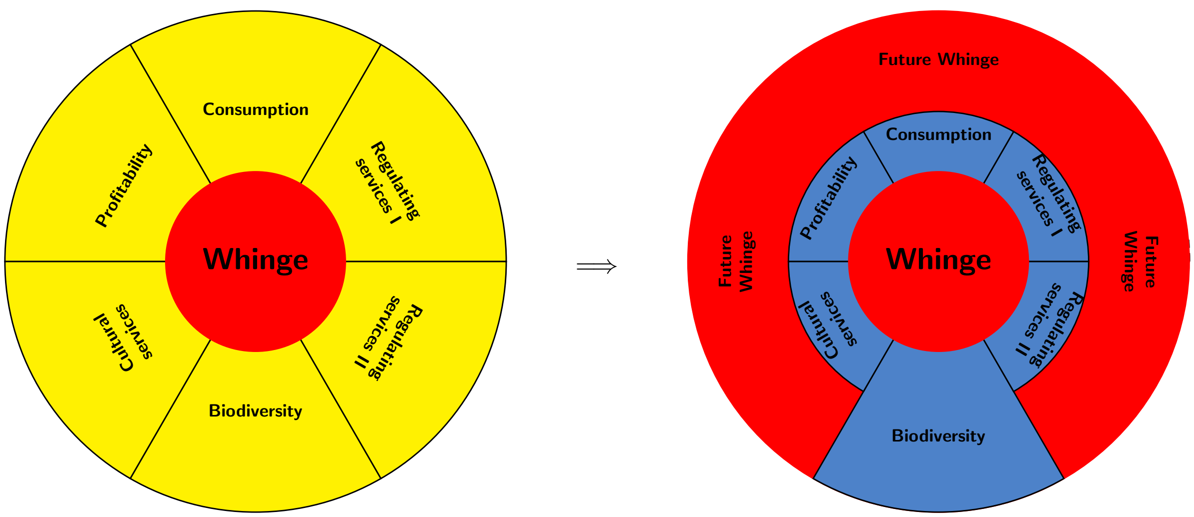

Figure 2: From the no whinge space (in yellow) to the no whinge kernel (in blue) taking the form of a tree of life or tree of viability. Most indicators or states (typically consumption on top) need to evolve within a safe corridor or window while biodiversity state just needs to have a viability floor.

The selection of no whinge thresholds

A key challenge of the minimal whinge approach involves turning broad conceptual objectives into quantifiable and measurable management constraints or targets, against which the performance of management strategies and scenarios can be assessed (Thébaud *et al.*, 2014). This specification of operational sustainability objectives requires three elements: performance indicators that specify the quantities of

[3]We implicitly assume that the level of floor thresholds are normalized.

interest, targets for the performance indicators, and measures of tolerance or acceptance that the indicator must achieve, usually specified as probabilities. However, given the uncertainty typical of most ecosystem management problems, and the diversity of stakeholders usually encountered in resource management systems, identifying performance indicators, targets and tolerance levels often proves a challenge in itself. Stakeholders may be unsure about which indicators, thresholds and tolerance levels should be retained, or they may disagree with respect to what these should be.

We propose here to use levels of status quo or 'Business as Usual' as indicators to specify the initial whinge boundaries and determine the 'mine pit' to avoid. Such an approach has already been applied in several viability works including Mouysset *et al.* (2014); Gourguet *et al.* (2016); Hardy *et al.* (2013); Cissé *et al.* (2015). Such a framework to design MSW thresholds has strong connections with no-regret strategy as introduced in Bell (1982). The various metrics used in the viability works previously mentioned combine indicators of biodiversity, catches and profits. Regarding profitability, the constraint has sometimes been relaxed to simply include positive rents. With regards to biological constraints, thresholds such as the ICES limits for fisheries can also be used. However it is clear that the governance of the socio-ecosystems at play requires flexibility and bargaining space between stakeholders to specify the whinge limits. We here argue that the flexibility should rely on tolerance values such the level of risks stakeholders are ready to cope with (Thébaud *et al.*, 2014).

Box B: A general model

A multi-state multi-pressure dynamic model under uncertainty. The social ecological system is described by a set of n stocks impacted by m distinct agents. The n stocks whose states at time t are denoted by $x_i(t)$ are governed by the following controlled and uncertain dynamic equations:

$$x_i(t+1) = f_i\big(x(t), c(t), \omega(t)\big), \tag{4}$$

for initial time $t = t_0$ to temporal horizon $t = T$. The global state $x(t)$ representing the ecosystem state is the vector of stocks $x(t) = (x_1(t), \dots, x_n(t))$. The vector $c(t) = (c_1(t), \dots, c_m(t))$ is the control of the system. The variables $\omega(t) = (\omega_1(t), \dots, \omega_p(t))$ represent the uncertainties (stochasticities) affecting the dynamics of the system. The functions f_i may account for various complexities including inter-specific competition or habitat impact.

The no whinge constraints. The viability approach focuses on the consistency of controlled dynamics of the system with respect to constraints capturing a no whinge space. These no whinge constraints can involve ecological thresholds as in population viability analysis (PVA). Economics constraints can also be integrated thus allowing for multi-criteria and bio-economic analyses as follows:

$$\left\{\begin{array}{rcll} \textsc{Biod}\big(x(t), \omega(t)\big) & \geq & \textsc{Biod}_{\lim} & \text{(biodiversity constraints)} \\ \textsc{Serv}\big(x(t), \omega(t)\big) & \geq & \textsc{Serv}_{\lim} & \text{(ecosystem services constraints)} \\ \pi_j\big(x(t), c(t), \omega(t)\big) & \geq & 0, & \text{(economic profitability)} \\ h\big(x(t), c(t), \omega(t)\big) & \geq & h_{\lim}(t), & \text{(food security)} \end{array}\right. \tag{5}$$

The total harvest $h(t)$ stems from catch of stocks i by agents j and depend on actions through production function

$$h_{ij}(t) = h_j\big(x_i(t), c_j(t), \omega(t)\big). \tag{6}$$

The food security constraint in (5) refers to some basic need standard denoted by $h_{\lim}(t)$ which may be time-dependent typically because of demographic growth. The economic profit $\pi_j(x(t), c(t), \omega(t))$ of each agent j is computed as the difference between the revenues derived from provisioning services $h_j(t)$ and operating costs associated with the decision $c_j(t)$; Note that these values are assumed to be random because of market price and cost (e.g. fuel) uncertainties. Ecological indicators $\textsc{Biod}(x(t), \omega(t))$ correspond to biodiversity or biological metrics. They can also be uncertain because of stock measurement errors. In that context the threshold $\textsc{Biod}_{\lim}$ can stand for an ecological tipping point. Similarly ecosystem services indicators $\textsc{Serv}(x(t), \omega(t))$ encompass regulating and cultural services induced by the ecosystem and the states of the system.
In contexts where uncertainties have a probabilistic nature, no whinge situations and bio-economic viability can be defined as the fulfillment of constraints with a high enough probability (De Lara & Doyen, 2008); namely

$$\mathbb{P}\big(\text{Constraints (5) are fulfilled for } t = t_0, .., T\big) > \beta \tag{7}$$

where β corresponds to a confidence rate (99%, ...) while probability $\mathbb{P}$ is computed with respect to uncertainty ω.

The no whinge kernel. A key mathematical tool is a again provided by the viability kernel. The viability kernel corresponds to a safe space within the initial set of constraints where the system needs to remain to be viable and to remain so in the future. It exemplifies the need for anticipating whinge crisis. In our stochastic context, this reads

$$\mathrm{Viab}_\beta = \left\{ x_0 \;\middle|\; \begin{array}{c} \text{there exist a strategy of feedback control } c(t,x) \\ \text{such that dynamics (4) and constraints (7) hold true} \end{array} \right\}. \tag{8}$$

Conclusion

This paper stresses the interest of both the no whinge approach and viability modeling for the sustainable management of ecosystems and socio-ecosystems. First, we argue that the no whinge approach (or minimal sustainable whinge) based on thresholds of ecological and socio-economic acceptability is in line with numerous approaches for operationalizing sustainability including SOS, SMS and TWA. Second we point out that the use of viability kernels makes possible the delineation of no whinge policies and scenarios accounting for the ecological-economic interactions and dynamics. The trees of viability derived from the viability kernel in our bio-economic context capture the idea that a bounded use of the different ecosystem services mixed with the unbounded renewal potential of biodiversity are pivotal ingredients for the sustainability of socio-ecosystems and the identification of no whinge policies avoiding the rejection of these policies from the different stakeholders involved. Of interest are also the room for manoeuvre, the adaptiveness and the open shape underlying the viability tree as opposed to the planetary space approach, the Oxfam doughnut or TWA which are characterized by more closed and limited forms.

Our approach rests on three domains of scientific advances in the fields of global change, sustainability and conservation. The first questions how human action, decision making and policies affect ecosystems and natural resources. The second aims at understanding ecosystem functioning, dynamics and processes driving ecosystem services for human well-being and development. The third field of enquiry is research into resilience and viable regulations of socio-ecosystems, emphasizing standards, constraints, guidelines, flexibility, governance and room for manoeuvre. These three domains constitute significant features of the ecological economics and conservation research agenda.

In particular, urgent research regarding ecological economics, no whinge and viability approaches relates to both applied and theoretical dimensions. From the applied viewpoint, the implementation on field with stakeholders using participatory approaches for fisheries, farming, forestry or water management is a major challenge. More specifically, the test of the 'viability tree hypothesis' mentioned above should constitute an interesting transversal perspective across these different case studies. From the theoretical viewpoint, the development of the ecosystem approach accounting for complex ecosystem dynamics including spatial and/or network components is a main challenge. Operationalizing sustainability and resilience by developing methods eliciting endogenous viability standards in a context of uncertainty including shocks, extreme events, stochasticities or ambiguities is also a key challenge. Which governance for the sustainability and resilience of ecosystems and socio-ecosystems is also a crucial task given the high heterogeneity of stakeholders involved in the environmental systems and the lack of coordination underlying the so-called tragedy of the commons ? In that respect, linking game theory, multi-agent methods with viability framework is a pivotal methodological task.

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