Ecosystem Service Trade-offs and Synergies

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Introduction

Much research has focussed on how a single (or at best a few) ecosystem service (ES) is supplied by certain ecosystems and/or demanded by certain groups. However, in reality, ecosystems or landscapes and their biodiversity provide multiple ecosystems services which also influence each other. For decision-making and management purposes, it is therefore of utmost importance to focus on all relevant ES, as well as to consider the relationships between them (e.g., Kandziora et al., 2013). When the simultaneous delivery of several desired/demanded ES is not possible, strongly inhibit each other, or initiate conflict, we talk about "ES trade-offs".

The term 'trade-off' appeared in the 1960s in economic theory (derived from the verb 'to trade off'). The term trade-off involves losing one quality or aspect of something in return for gaining another quality or aspect. It is now more generally used for situations where a choice needs to be made between two or more things that cannot be had at the same time.

Trade-off is also a very popular term in the ES literature, but covers a wider array of phenomena, such as conflicting land-uses, a negative correlation between spatial occurrences of ES, ES incompatibilities, rivalry and excludability of ES, etc. Despite its popularity, the intuitive definition of 'ES trade-offs' and its antonym 'ES synergies' lack conceptual clarity. When moving from theoretical concepts towards scientific comparison, more analytic definitions are required. In this SP, we further explore the trade-offs and synergies between ecosystem services, which often boil down to trade-offs between benefits and well-being components (Iniesta-Arandia et al., 2014), value dimensions (e.g. Martín-López et al., 2014), or management strategies (McShane et al. 2011).

Concept and definition

To better delineate the ES trade-off concept, we propose two criteria. First, ES trade-offs or synergies only occur if the considered ES interact with each other. This may be due to simultaneous responses to the same driver or due to true interactions among ES (Bennett et al., 2009). Drivers could include ES use, ecological changes, management regime, investment choices, etc. Up until now, ES trade-offs and synergies are commonly assessed based on spatial or temporal co-occurrence of ES supply, and often there are no direct links between such co-varying services. Patterns of spatially or temporally co-varying ES are defined as 'ES bundles' (Berry et al., 2015). Another difference with ES bundles is that for ES trade-offs it is not essential that the interacting ES occur at the same time and/or same location (e.g. effects of upstream land-use conversion for agriculture on downstream flood risk) (García-Llorente et al., 2015).

Second, understanding ES trade-offs and synergies requires more than assessing (potential) supply and assessing (potential) demand (Geijzendorffer et al., 2015). An interaction between ES is only invoked whenever an ES is "used", meaning that the ecosystem is somehow managed/altered/accessed/ protected/ experienced as a result of a demand. Such a physical intervention is the causal mechanism by which a trade-off (or synergy) is provoked: this 'use' of one service changes access to, supply of or demand for another service(s). Trade-offs and synergies thus involve aspects of both supply, demand and use (Figure 1). Often in the literature these aspects are considered separately. Examples are: variability of potential supply (determined by ecological functional aspects or biophysical incompatibilities), competing ES-demands (determined by interactions between stakeholders, e.g. power relationships), imbalances between demand and supply (e.g. unsatisfied ES demand). In these examples there is no actual 'trading off' taking place, therefore they can be considered 'ES mismatches'. These ES mismatches can be a prelude to ES trade-offs, but by themselves do not yet represent ES trade-offs.

Based on the above, and building on interpretations of, for example, Rodriguez et al. (2005, 2006), Bennett et al. (2009), Howe et al. (2014), the following definitions are suggested:

- A **trade-off** is 'a situation where the use of one ES directly decreases the benefits supplied by another. A change of ES use could be triggered by the demand and/or the supply side. A trade-off could take place in the same place or in a different area (e.g. impact of the management of a forest for wood production on local recreation and downstream water quality). A special case is a trade-off between the present and future use of the same ES (e.g. overharvesting of fish stock).
- A **synergy** is 'a situation where the use of one ES directly increases the benefits supplied by another service' (e.g. impact of the protection of coral reef area on fish abundance, which increases algal grazing and thus protects the coral, which eventually enhances recreation opportunities).

To make the distinction clear between the related concepts, we quote the definition of ES bundles (Berry et al., 2015): *'a set of associated ecosystem services that are linked to a given ecosystem and that usually appear together repeatedly in time and/or space'*. For ES bundles interaction between ES is therefore not essential. Multifunctionality is defined as *'the characteristic of ecosystems to simultaneously perform multiple functions that might be able to provide a particular ES bundle or bundles'.*

In Figure 1, the analytical links between these concepts and the trade-off mechanism are visualized. On one hand, an ecosystem is usually multi-functional, enabling the potential supply of several ES (= ES bundle). There may be limits to the *actual* supply of ES bundle(s) due to constraints on the ability of the ecosystem to deliver each service to the required level, due to biophysical drivers (e.g. disease, climate change, invasive species), management practices, and/or the negative interactions between certain ES. On the other hand, one of the major driving forces of ecosystem management, use and structure (especially in modified landscapes) is the stakeholder demands and desires (Mouchet et al., 2014). The use of the ecosystem invokes ES interactions which potentially lead to synergies and/or trade-offs. A trade-off can potentially result in a conflict between users depending on who bears the burden and who benefits of the ES supply (TEEB, 2010; Kandziora et al., 2013). In the case of ES synergies or when ES are not interacting or when stakeholders want to avoid conflict, the interaction between users may vary between co-existence to cooperation. The actual use choices depend on power relationships among stakeholders (Felipe-Lucía et al., 2015) and on institutional and knowledge mechanisms that mediate the interactions between stakeholders and with their environment (Hicks and Cinner, 2014) with consequences for equity and social justice (see SP on social justice).

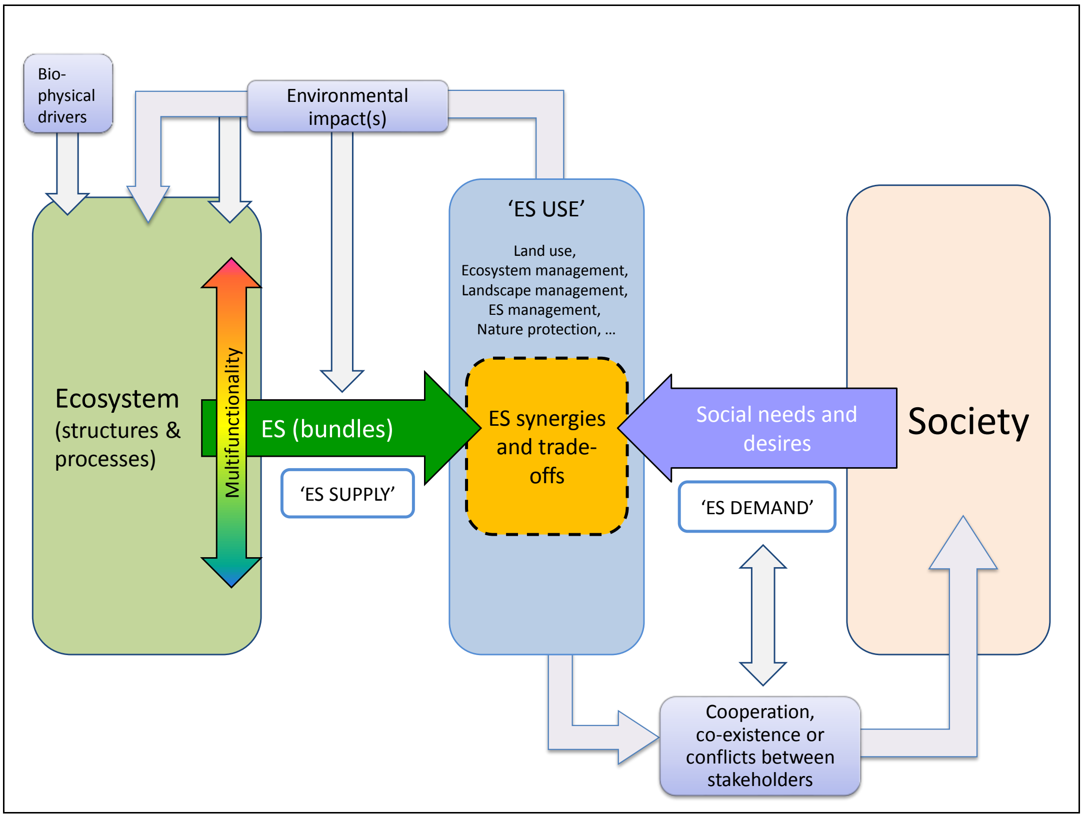

Figure 1: Visualisation of analytical links between related concepts and the trade-off mechanism.

Trade-off analysis

Managing multiple ES, while taking into account these trade-offs and synergies, requires disentangling the underlying mechanisms of these ES interactions, e.g. identifying common supporting functions, responses to common pressures,functional interactions among services (Bennett et al., 2009). Regional level studies can apply meta-review techniques to provide indications of potential trade-offs (see example by Howe et al., 2014). A methodological roadmap for quantifying ES synergies and trade-offs on the supply and demand sides has been recently published (Mouchet et al., 2014). Different quantitative statistical methods are often used to assess trade-offs (see Mouchet et al., 2014 for a review), but often they do not fully capture the highly context-dependent mechanisms of trade-offs and synergies. The explanatory variables for observed ES relationships can be attributed to social, economic, institutional and ecological factors, which are also highly context-specific. Thus place-based studies are required which focus on the local specificities of trade-off mechanisms, while taking into account both supply and demand. The involvement of local knowledge of experts and stakeholders is often the most efficient and reliable way to identify and explain ES trade-offs. As this kind of studies is rather rare, it is not surprising that knowledge about when to expect trade-offs or synergies, the mechanisms that cause them, or how to minimize trade-offs and enhance synergies currently is lacking (Bennett et al., 2009; Ostrom, 2009; Howe et al., 2014).

Analysing trade-offs entails some challenges, such as:

(1) the complexity of ES interactions and the factors determining them,

(2) different value-dimensions of ES (biophysical, socio-cultural and economic) provide different information and thus different trade-offs (Castro et al., 2014; Martín-López et al., 2014, see also OpenNESS Deliverables D4.1 and D4.3),

(3) future trade-off(s) between ES entail uncertainties (especially when dealing with time lags and spatial discontinuities) which are difficult to assess, and

(4) the spatial and temporal scale dependence of ES trade-offs (Rodriguez et al., 2006; Renard et al., 2015).

Operationalization of ES trade-offs

In a literature review, Howe et al. (2014) identified that ES trade-offs are mentioned roughly three times more than ES synergies (149 vs 45). Stakeholder groups also report proportionally more trade-offs than synergies (Hicks et al., 2013).

Trade-offs between provisioning and regulating ecosystem services at different scales have been a main cause for concern, because regulating ecosystem services are thought to underlie the sustainable production of provisioning and cultural ecosystem services and are important for the resilience of social-ecological systems (Raudsepp-Hearne et al., 2010; García-Llorente et al., 2012; Castro et al., 2014). There is also evidence that trade-offs among services vary across different landscape types. Landscape types representing ecosystems with intermediate human intervention (such as agricultural terraces, wood pastures or oak *dehesas*) were perceived as aesthetically pleasant, highly valued, and multi-functional. Meanwhile, intensified systems - focusing on the delivery of a single provisioning service - were less valued by society (García-Llorente et al., 2012).

Better understanding of the underlying mechanisms and motivations for trade-offs and synergies can be beneficial for planning and managing ES, because it can help to:

(1) predict where and when trade-offs might take place,

(2) reduce undesirable trade-offs and related conflicts,

(3) enhance desirable synergies (e.g. by management strategies which are able to simultaneously deliver several desired ES),

(4) promote honest dialogue, creativity, and learning between concerned stakeholder groups,

(5) lead to more effective, efficient and credible management decisions, and

(6) obtain more equitable and fair outcomes by taking into account distributive impacts of ES trade-offs (e.g. in PES schemes) (Rodríguez et al., 2006; Bennett et al., 2009; Nelson et al., 2009; Hirsch et al., 2010; Raudsepp-Hearne et al. 2010; Elmqvist et al., 2011; McShane et al., 2011; Phelps et al., 2012; Hicks et al., 2013).

Problems / Issues to be discussed during the lifetime of OpenNESS

1. How does ecosystem management affect ES trade-offs and synergies and their consequences? Can we identify leverage points where a small change in management can reduce the impact of ES trade-offs and enhance synergies?
2. How to reduce the potential risk of policy failure due to ES trade-offs and the uncertainty they entail?
3. How can power asymmetries among stakeholders be addressed to influence the handling and resolution of ES trade-offs?
4. How to better account for long term ecological, social and cultural implications of trade-offs between economy and environment in decision making processes?

Significance to OpenNESS and specific Work Packages

WP1: It is important that trade-offs are integrated into ES concepts, frameworks and their operationalization (an example is provided in Fig. 1).

WP2: Assessing whether ES trade-offs are considered within and between existing and forthcoming EU and national regulatory frameworks addressing ES. How can individual or a mix of policy interventions mitigate or manage the impacts of ES trade-offs and feedback processes at different scales?

WP3: In order to avoid unexpected changes, it is important that we improve the understanding of the functioning of ecological processes which are important for service supply and ES trade-offs (Bennett et al., 2009). How to integrate ES trade-offs and synergies into ES assessments and tools?

WP4: How well do the hybrid and integrated valuation methodologies being developed in OpenNESS enable the valuation of trade-offs?

WP5: For future land-use plans or interventions in the case studies, it is important that the trade-offs are fully considered and assessed.

WP6: How can the implications of ES trade-offs be translated into policy recommendations and integrated into the Menu of Multi-Scale Solutions and associated datasets?

Relationship to the four challenges

Human well-being: When ES that are important for human well-being are affected by trade-offs or synergies, then well-being will be affected.	**Sustainable Ecosystem Management (SEM):** It is often not possible for SEM to achieve all management objectives and fulfil all public expectations. Therefore it is essential to make trade-offs explicit and find appropriate ways to deal with them.
Governance: To be effective, cross-sectoral policies and governance need to consider (potential) ES trade-offs and their distributional impacts.	**Competitiveness:** The private sector need to consider trade-offs in their daily management decisions. ES can be traded-off against other business priorities. However, if this is impacting supporting ES on which a business depends, their long-term profitability can be affected. In case these decisions impact ES important for society, reputation damage will be the result.

Recommendations to the OpenNESS consortium:

The proposed concept and definition is new, and is the result of internal consultation. It is proposed that OpenNESS members explore and further improve this trade-off concept in the WPs and the case studies. If this approach is found to be useful, then it is recommended that OpenNESS accept it in the glossary and in the practise of OpenNESS.

It is recommended that for the analysis and development of multifunctional ecosystems or landscapes, trade-offs and all its implications are fully taken into consideration.

Suggested three "must read" papers:

Bennett E.M. et al. (2009): Understanding relationships among multiple ecosystem services. *Ecology letters* **12(12)**: 1394-1404.

Howe C. et al. (2014): Creating win-wins from trade-offs? Ecosystem services for human well-being: A meta-analysis of ecosystem service trade-offs and synergies in the real world. *Global Environmental Change***28**: 263-275.

Mouchet M. et al. (2014): An interdisciplinary methodological guide for quantifying associations between ecosystem services. *Global Environmental Change* **28:** 298-308.

Further Cited papers:

Berry P. et al. (2015): Ecosystem Services Bundles. In: Potschin, M. and K. Jax (eds): OpenNESS Ecosystem Services Reference Book. EC FP7 Grant Agreement no. 308428. Available via: www.openness-project.eu/library/reference-book

Castro A.J. et al. (2014): Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis. *Landscape and Urban Planning* **132**: 102-110.

Elmqvist T. et al. (2011): Managing Trade-offs in Ecosystem Services. Ecosystem Services Economics (ESE) Working Paper Series.Division of Environmental Policy Implementation Paper N° 4.The United Nations Environment Programme.

Felipe-Lucía M. et al. (2015):Ecosystem services flows: why stakeholders' power relationships matters. *PLoS ONE* **10(7)**: e0132232.DOI:10.1371/journal.pone.0132232

García-Llorente M. et al. (2012): The role of multi-functionality in social preferences toward semi-arid rural landscapes: An ecosystem service approach. *Environmental Science & Policy* **19-20**: 136-146.

García-Llorente M. et al. (2015): Biophysical and socio-cultural factors underlying spatial tradeoffs of ecosystem services in semiarid watersheds. *Ecology and Society* 20 (3):39.

Geijzendorffer I.R. et al. (2015): Improving the identification of mismatches in ecosystem services assessments. *Ecol. Indic*. **52**, 320–331.

Hicks C. and Cinner J. (2014): Social, institutional, and knowledge mechanisms mediate diverse ecosystem service benefits from coral reefs. *Proceedings of the National Academy of Sciences of the United States of America* (*PNAS)* **111 (50)**: 17791-17796.

Hicks C.C. et al. (2013): Synergies and trade-offs in how managers, scientists, and fishers value coral reef ecosystem services. *Global Environmental Change* **23(6)**: 1444-1453.

Hirsch P.D. et al. (2010): Acknowledging Conservation Trade-Offs and Embracing Complexity. *Conservation Biology* **25(2)**: 259-264.

Iniesta-Arandia I et al. (2014): Socio-cultural valuation of ecosystem services: uncovering the links between values, drivers of change and human well-being. *Ecological Economics* 108:36-48.

Kandziora M. et al. (2013): Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators—A theoretical matrix exercise. *Ecological Indicators* **28:** 54-78.

Martín-López B. et al. (2014): Trade-offs across value-domains in ecosystem services assessment. *Ecological Indicators* **37** 220– 228.

McShane T.O. et al. (2011): Hard choices: making trade-offs between biodiversity conservation and human well-being. Biol. Conserv. 144, 966–972.

McShane T.O. et al. (2011): Hard choices: Making trade-offs between biodiversity conservation and human well-being. *Biological Conservation* **144(3)**: 966-972.

Nelson E. et al. (2009):Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment* **7(1)**: 4-11.

Ostrom E. (2009): A general framework for analyzing sustainability of social-ecological systems. Science **325:** 419-422.

Phelps J. et al. (2012): Win–win REDD+ approaches belie carbon–biodiversity trade-offs. *Biological Conservation* **154**: 53-60.

Raudsepp-Hearne C. et al. (2010): Ecosystem service bundles for analyzingtradeoffs in diverse landscapes. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)* **107(11)**: 5242-5247.

Renard D. et al. (2015): Historical dynamics in ecosystem service bundles. Proceedings of the National Academy of Sciences of the United States of America (PNAS) **112(43)**: 13411-13416.

Rodriguez J.P. et al. (2005): Interactions among Ecosystem Services.Ecosystems and human well-being: scenarios 431–448.Chapter 12 -Interactions among Ecosystem Services.In Ecosystems and Human well-being: scenarios, volume 2. Millennium Ecosystem Assessment, Island Press: 431-448.

Rodríguez J.P. et al. (2006): Trade-offs across Space, Time, and Ecosystem Services. *Ecology and Society* **11(1)**: 28.

TEEB (2010): The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Edited by P. Kumar Earthscan, London and Washington.

Review Editor: Marion Potschin (UNOTT)

Suggested Citation: Turkelboom F., Thoonen M., Jacobs S., García-Llorente M., Martín-López B. and Berry P. (2015): Ecosystem services trade-offs and synergies (draft). In: Potschin, M. and K. Jax (eds): OpenNESS Reference Book. EC FP7 Grant Agreement no. 308428. Available via: www.openness-project.eu/library/reference-book

Acknowledgements: The following OpenNESS partners have further contributed to the SP: Francesc Baro (UAB), David Odee (KEFRI), Camino Liquete (JRC), Conor Kretsch (UNOTT), Bálint Czúcz (MTA ÖK), Raktima Mukhopadhyay (IBRAD), Vesa Yli-Pelkonen (UH), Roy Haines-Young (UNOTT)

Disclaimer: This document is a preliminary but 'stable' working document for the OpenNESS project. It has been consulted on formally within the consortium. It is not meant to be a full review on the topic but represents an agreed basis for taking the work of the project forward. Its content may, however, change as the results of OpenNESS emerge. A final version, incorporating all the new material will be published at the end of project in 2017.