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Research article

A cooperative game-theoretic framework for negotiating marine spatial allocation agreements among heterogeneous players

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ABSTRACT

Marine spatial allocation has become, in recent decades, a political flashpoint, fuelled by political power struggles, as well as the continuously increasing demand for marine space by both traditional and emerging marine uses. To effectively address this issue, we develop a decision-making procedure, that facilitates the distribution of disputed areas of specific size among heterogeneous players in a transparent and ethical way, while considering coalitional formations through coexistence. To do this, we model players' alternative strategies and payoffs within a cooperative game-theoretic framework. Depending on whether transferable utility (TU) or non-transferable utility (NTU) is the more appropriate assumption, we illustrate the use of the TU Shapley value and the Lejano's fixed point NTU Shapley value to solve for the ideal allocations. The applicability and effectiveness of the process has been tested in a case study area, the Dogger Bank Special Area of Conservation in the North Sea, which involves three totally or partially conflicting activities, i.e. fishing, nature conservation and wind farm development. The findings demonstrate that the process is capable of providing a unique, fair and equitable division of space Finally, among the two solution concepts proposed the fixed point NTU Shapley value manages to better address the heterogeneity of the players and thus to provide a more socially acceptable allocation that favours the weaker player, while demonstrating the importance of the monetary valuation attributed by each use to the area.

1. Introduction

Over the last decades, the increasing demand for marine space for economic development and environmental protection has led to the urgent need to address potential marine spatial conflicts (Douvere, 2008). The best process to deal with conflicting claims for the same area is marine spatial planning (MSP). MSP is an ecosystem-based spatial organization process towards sustainability, that aims to integrate economic sectors, social demands and environmental protection, while promoting active participation of stakeholders and transparent governmental decision-making. It posits a strategic long-term time horizon and it is considered a type of adaptive governance (Ehler and Douvere, 2007). Hence, among the main objectives of MSP, is the coordination of marine activities and the solution of allocation problems that could potentially lead to spatial conflicts.

Allocation problems arise whenever a bundle of resources, rights, burdens, benefits or costs, held temporarily in common by a group of individuals, must be distributed among them. It usually requires two different types of decisions: (a) the choice of the total amount of the resource to be distributed; and (b) the formula, principle or rule applied to allocate that amount (Young, 1994). The problem of dividing a desirable resource is also called the cake-cutting problem wherein a cake is a metaphor for a heterogeneous, divisible good, whose parts may be valued differently by different people (Brams et al., 2006). Simple rules for a fair division among agents with legitimate (but possibly unequal) claims in case the total quantity of goods available is inadequate for meeting all the claims, has been studied extensively in the literature (Young, 1994; Brams and Taylor, 1996; Moulin, 2003; Thomson, 2011).

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The challenge is to choose an appropriate allocation rule within a wider spatial decision making processes, where marine users interact between each other in order to reach a spatial allocation agreement. To ensure such an agreement, the chosen allocation rule should guarantee: a) (Pareto) efficiency, where all claimed space is allocated among the various claimants and it is impossible to make one of them better off without making at least one other worse off; b) optimization that ensures the maximization of the allocated benefit to the claimants; c) fairness and equity that ensures all claimants are satisfied with the allocation; and d) long-term cooperation (Hougaard, 2009). However, an agreement over a spatial plan is also affected by the number of the claimants involved, their role and type, their political influence and power, their interdependences, their ability to communicate, the coalitions they might form, their intention to cooperate and to agree on mutually beneficial (win-win) allocations (Kilgour and Eden, 2010). Furthermore, the level of trust, learning, norms, their preferences and perceptions and their local and traditional knowledge (Pomeroy and Douvere, 2008; Cerreta et al., 2010) also play a crucial role.

All of the above elements are well captured by cooperative game-theoretic modelling techniques that are able to consider the potential of the formation of cooperative structures with and without side payments (compensation), to capture coalitional dynamics, and to facilitate win-win results using a variety of allocation rules (Myerson, 1991) (which are commonly referred as cooperative game-theoretic solution concepts).

Cooperative game theory has been used to model and solve allocation of natural resources, such as fisheries (Baileya et al., 2010), water (Madani, 2010), forests (Kant and Nautiyal, 1994) and land (Martin and Wise-Bender, 1990; Dufwenberg et al., 2016). A number of such applications are also presented in Parrachino et al. (2006), Zara et al. (2006) and Dinar et al. (2008). It is also popular in the development of climate change policies (Carraro and Massetti, 2013) and international biodiversity conservation agreements (Barrett, 1994; Gatti et al., 2011). In a spatial context it has been used for the fair and equitable siting of noxious facilities (Marchetti, 2003; Lejano and Davos, 2001, 2002). In the coastal management context it has been employed by Davos and Lejano (2001). Regarding MSP however, so far cooperative game theory has only been applied for the designation of marine protected areas (Punt et al., 2010) and the assessment of spatial co-location of marine activities (Kyriazi et al., 2015). In contrast, approaches based on spatial prioritization such as trade-off analysis (see for example White et al., 2012; Lester et al., 2013) and multi-criteria analysis combined with participatory and negotiation processes, are more popular for marine spatial planning (see applications for instance from Alexander et al., 2012; Tuda et al., 2014; Dapueto et al., 2015; Janssen et al., 2015; Yates et al., 2015; a review of similar tools in Coleman et al., 2011).

The relevance of cooperative game-theoretic modelling to marine space allocation can be further demonstrated by the fact that marine space resembles common pool resources (CPR), in the sense that space is limited too and the more it is occupied by certain users the less it is available for others. Three basic ways of addressing the commons problem have been identified (Madani and Dinar, 2012) i.e. assumptions involving a) non-cooperation, b) exogenously regulated or c) cooperation. Under non cooperative behaviour, beneficiaries will seek to maximize their own benefits ignoring the long-term effects of resource overexploitation and the negative externalities for the rest of the society. This situation might lead to the tragedy of the commons (Hardin, 1968) a phenomenon that can be addressed either through interventions by regulators (e.g., regulation of use, ownership rights assignment, and enforcement of different CPR governing rules) (Madani and Dinar, 2011; Abatayo and Lynham, 2016) or through the development and enforcement of collective actions that ensure long term collective gains (Ostrom, 1990). The last can be modelled with cooperative game theory.

Generally, cooperative games are multi-player (n person) games, involving a finite number N of players, where $|N| = n > 1$, who are allowed to communicate and make binding agreements (Von Neumann and Morgenstern, 1944). These players may represent stakeholders or decision makers in a resource or spatial allocation problem. In the case of marine space, players may include, but are not limited to, countries, states, or individuals such as industrial managers, fishermen and nature conservation managers. In any n player game there are 2^{n-1} possible coalitions which may form. A coalition here is perceived as an agreement between two or more players to share an area. The benefit from this agreement is called the value v of the coalition that the players will divide between each other using a chosen allocation rule or solution concept (Myerson, 1991) (described below). This value might reflect e.g. the size of the area in km^2 or the monetary value attributed to the area by the players operating inside area.

Based on above elements and on the evidence from literature about the effectiveness of cooperative game theory in specific allocation contexts (Lejano and Davos, 1999), we developed a decision-making process, that facilitates the distribution of disputed areas among heterogeneous players using cooperative game-theoretic assumptions, axioms and solution concepts. The usefulness and effectiveness of the process is demonstrated in a case study of multi-party negotiations around the Dogger Bank in the North Sea.

The paper is divided into the following sections: Section two is methodological and it presents the solution concepts chosen as more relevant to the process and the detailed description of the process. In the same section, the case study is briefly presented, along with the specific issues that the process will address. In section three the application of the process and the solutions are presented. Section four discusses the results pointing out the strength of the process to tackle the problem at hand. In the fifth section conclusions along with policy implications are demonstrated and future research that uses the findings of the present paper as a starting point is proposed.

2. Developing a cooperative marine spatial allocation process (CMSAP)

2.1. Choosing among transferable utility and not transferable utility games

Two important types of cooperative games exist: those with transferable utility (TU), where transfer payments (also called side payments) between players are possible and are allowed, and those with non-transferable utility (NTU), where transfer payments are not possible or not allowed (Peleg and Sudhölter, 2007). A TU game assigns a value (or scalar) to each coalition, where this value is the total aggregate amount that the coalition of players can assure for itself by cooperating and that can be shared by the players through transfer (side) payments. Thus, a TU game is an ordered pair, (N,v) corresponding to a set of players, N and a scalar-valued characteristic function $v{:}2^n \rightarrow R^n$, such that for every coalition $S \in N$, v assigns a value, $v(S) \in R$, and $v(\varnothing) = 0$ (Lejano, 2011). In contrast, an NTU game assigns a set (or vector) of outcomes to each coalition, where each outcome states the payoff to each player in the coalition. Thus, an NTU game is a pair (N,V) corresponding to a finite set N, of players and a set-valued characteristic mapping $V{:}2^n \rightarrow R^n$, such that for every coalition $S \in N$, V assigns a set $V(S) \in R^{|S|}$ (Lejano, 2011).