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Evaluation of ecosystem-based marine management strategies based on risk assessment

Gerjan J. Piet [a,*], Ruud H. Jongbloed [a], Antony M. Knights [b,1], Jacqueline E. Tamis [a], Anneke J. Paijmans [a], Marieken T. van der Sluis [a], Pepijn de Vries [a], Leonie A. Robinson [b]

[a] *Institute for Marine Resources and Ecosystem Studies (IMARES), Haringkade 1, 1976 CP IJmuiden, The Netherlands*
[b] *School of Environmental Sciences, University of Liverpool, Nicholson Building, Liverpool L69 3GP, UK*

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ABSTRACT

This study presents a comprehensive and generic framework that provides a typology for the identification and selection of consistently defined ecosystem-based management measures and allows a coherent evaluation of these measures based on their performance to achieve policy objectives. The performance is expressed in terms of their reduction of risk of an adverse impact on the marine ecosystem. This typology consists of two interlinked aspects of a measure, i.e. the "Focus" and the "Type". The "Focus" is determined by the part of the impact chain (Driver–Pressure–State) the measure is supposed to mitigate or counteract. The "Type" represents the physical measure itself in terms of how it affects the impact chain directly; we distinguish Spatio-temporal distribution controls, Input and Output controls, Remediation and Restoration measures. The performance of these measures in terms of their reduction in risk of adverse impacts was assessed based on an explicit consideration of three time horizons: past, present and future. Application of the framework in an integrated management strategy evaluation of a suite of measures, shows that depending on the time horizon, different measures perform best. "Past" points to measures targeting persistent pressures (e.g. marine litter) from past activities. "Present" favors measures targeting a driver (e.g. fisheries) that has a high likelihood of causing adverse impacts. "Future" involves impacts that both have a high likelihood of an adverse impact, as well as a long time to return to pre-impacted condition after the implementation of appropriate management, e.g. those caused by permanent infrastructure or persistent pressures such as marine litter or specific types of pollution.

1. Introduction

All marine ecosystems are impacted by human activities (e.g. Glover and Smith, 2003; Halpern et al., 2007) and in many cases, the exploitation of resources is occurring at an unsustainable rate resulting in a deteriorated ecosystem. Impacts are caused by the multitude of sectors in operation to exploit a wide range of habitats and species (ecosystem components), thereby forming a complex network of interactions (Leslie and McLeod, 2007; Liu et al., 2007; Knights et al., 2013) that may cause harm to the environment (Levin et al., 2009; Goodsir et al., in press). This has left current sectoral approaches to the management of marine and coastal resources apparently incapable of conserving the marine ecosystem and exploitation rates remaining unsustainable (Smith et al., 2007). A widely promoted solution is an ecosystem approach to management also known as ecosystem-based management (EBM) (Airoldi and Beck, 2007; EC, 2008; Halpern et al., 2007); a concept in which the network of impacts is identified and managed. However, the number of impacts can make the identification and management of detrimental pathways difficult (Bottrill et al., 2008) and presents a major challenge to resource managers in transforming the ecosystem approach from a concept into an operational framework (Leslie and McLeod, 2007). This challenge can be addressed by the development of a comprehensive generic framework for integrated decision-making on the exploitation of marine resources.

The effective management of human impacts requires that the pathways through which activities cause harm are identified (Fletcher et al., 2010; Leslie and McLeod, 2007). Linkage-based frameworks (e.g. DPSIR) have been developed for marine and terrestrial environments (Elliott, 2002; Holman et al., 2005; La Jeunesse et al., 2003; Odermatt, 2004; Scheren et al., 2004),

* Corresponding author at: Wageningen IMARES, P.O. Box 68, 1970 AB IJmuiden, The Netherlands. Tel.: +31 (0)317 487188.
E-mail address: gerjan.piet@wur.nl (G.J. Piet).
[1] Present address: Marine Biology and Ecology Research Centre, Plymouth University, Drake Circus, Plymouth, UK.

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adopting a causal-chain approach to infer pressure-state relationships between human activities and ecosystem state (Rounsevell et al., 2010). The number of potential links between sectors and the state of the ecosystem (Airoldi and Beck, 2007; Knights et al., 2013) can increase the difficulty of decision-making, especially when time is limited (Haynes, 2009). In support, several frameworks for formal decision-making are available (Jeffrey, 1983, 1992; Resnik, 1987) with risk assessment in particular providing a flexible, problem-solving approach that is capable of linking the relationship between human activities and the environment supporting the decision-making needs of environmental managers (Hope, 2006). Risk assessment in general describes the likelihood and consequences of an event. In the context of EBM, it evaluates the degree to which human activities interfere with the achievement of management objectives that are related to particular ecological characteristics (Hobday et al., 2011; Samhouri and Levin, 2012) and is increasingly seen as a way to integrate science, policy and management (CENR, 1999).

To date, risk assessment has been used to assess a wide range of environmental issues. Early efforts addressed a single ecosystem component and considered few threats (e.g. Francis, 1992), followed by more comprehensive frameworks that were developed for species (e.g. Kappel, 2005; Samhouri and Levin, 2012) or features (e.g. Zacharias and Gregr, 2005; Halpern et al., 2007). In none of these cases was a specific link to existing environmental policy made. But in perhaps the most extensive framework to date, Driver–Pressure–State combinations for entire ecosystems were developed (Robinson et al., 2013; Knights et al., 2015) and these combinations (which were referred to as "impact chains") were explicitly linked to existing policy objectives, namely the Marine Strategy Framework Directive (MSFD) and its qualitative descriptors of good environmental status (GES) (EC, 2008). Assessing the risk to an ecosystem from a particular impact chain can be done using quantitative approaches (e.g. Francis, 1992; Samhouri and Levin, 2012) or qualitative approaches (e.g. Breen et al., 2012; Fletcher, 2005; Fletcher et al., 2010). Ecological risk assessments (e.g. Fletcher, 2005; Campbell and Gallagher, 2007; Astles et al., 2006) tend to be based on a likelihood-consequence approach for estimating the risk of a rare or unpredictable event (i.e. calamities) (Williams et al., 2011). However, when an assessment of on-going (current) pressure is needed (i.e., normal operations, where the likelihood equals 100%), then an exposure-effect analysis is more suitable (Smith et al., 2007) using qualitative descriptors such as habitat resistance and resilience to assess the vulnerability of habitats (Bax and Williams, 2001) and more recently, assess the potential for EBM at a sub-regional scale (Samhouri and Levin, 2012).

Building on the vulnerability measures of Halpern et al. (2007), Robinson et al. (2013) conducted a qualitative pressure assessment that assessed the threat from different driver–pressure combinations to the state of the ecosystem components (thus making up impact chains) for all European regional seas. From this, Knights et al. (2015) used an exposure-effect analysis with five criteria to assess risk for each impact chain which can be interpreted as the likelihood or degree to which human activities interfere with the achievement of policy objectives. Risk can then be assessed for each Driver, Pressure or State component through aggregation across those impact chains that include that particular Driver, Pressure or State component. This, in turn, allows for an evaluation of how risk will decrease over time once management on one or more of these components or combinations of components is implemented.

The logical next step toward achieving policy objectives is the choice of appropriate ecosystem-based management (EBM) measures to mitigate those risks affecting these objectives (Samhouri and Levin, 2012). To that end we developed a comprehensive framework for integrated Management Strategy Evaluations (iMSE) framework that links directly to the risk assessment approach described (e.g. Halpern et al., 2007; Knights et al., 2015), providing guidance for the identification and selection of consistently defined measures, and also allowing an evaluation of the effectiveness of these measures through their reduction of risk. For this, the effectiveness of a management measure depends on both (a) the number of impact chain(s) it targets; (b) the weighting of the chains based on the five risk criteria; and (c) the likelihood the measure can reduce the impact of these chains. Measures that target a selection of impact chains that together contribute a high proportion of the risk to the ecosystem being assessed are likely to be most effective.

2. Material and methods

2.1. Summary of risk assessment approach

This framework for the identification, selection and evaluation of management measures (MMs) is based on the most extensive risk assessment approach to date consisting of Driver–Pressure–State combinations (so-called "impact chains") that each contribute to the risk of not achieving policy objectives (Knights et al., 2015). Risk is determined based on scores given to five criteria. These are: (1) the spatial (Extent), and (2) temporal (Frequency) overlap of a sector-pressure and ecological characteristic, which together describe the exposure of the ecological component to a sector-pressure combination in terms of their spatio-temporal overlap; (3) the Degree of Impact (DoI) of the sector-pressure on that characteristic describing the severity of the impact where interactions occur; whilst the potential for recovery after the impact has occurred is described by (4) the Persistence of the pressure (the number of years before the pressure impact ceases following cessation of the activity introducing it), and (5) the Resilience of the ecological characteristic (recovery time in years) (see full details of criteria in Robinson et al., 2013). Based on these criteria, Knights et al. (2015) allocated scores and considered two aspects of risk:

- Impact Risk (IR) = the likelihood of an adverse ecological impact following a sector-pressure introduction = Extent $*$ Frequency $*$ DoI.
- Recovery Lag (RL) = a relative indication of the time it takes for an impacted ecological component to return to pre-impacted condition after the implementation of a measure = Persistence $*$ Resilience.

2.2. Selection of MMs

As MMs tend to either reduce the exposure to a pressure, the severity of impacts where there are interactions, or actively promote recovery, it is possible to select measures using the five criteria described above, and thus to target particular aspects of risk in the ecosystem (Fig. 1). Linked to these risk assessment criteria, the selection of MMs can then also be guided by two distinct aspects of a MM: the "Focus" and the "Type" of measure. The "Focus" is determined by the element(s) of the impact chain (i.e. Driver–Pressure–State) that the measure targets. A measure may involve only one single element in the impact chain (i.e. Driver, Pressure or State), the combination of two (i.e. Driver–Pressure or Pressure–State), or all three making the measure more specific as more elements are combined (see first column in Fig. 1 and examples in Table 1). "Type" consists of six categories of measures, loosely based on the measures distinguished in (EC, 2008), that mitigate or counteract the impact of the human activity on the