Fisheries Research 182 (2016) 28–38

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Building Bayesian Belief Networks to investigate how fishery performance responds to management interventions

Fiona M. Underwood [a,*], Graeme Parkes [b], Jill H. Swasey [c]

[a] Independent Statistical Consultant, Visiting Senior Research Fellow at the University of Reading, UK
[b] MRAG Americas, Inc., 10051 5th Street North, Suite 105, St. Petersburg, FL 33702, United States
[c] MRAG Americas, Inc., 65 Eastern Avenue B2C, Essex, MA 01929, United States

ARTICLE INFO

Article history:
Received 14 May 2015
Received in revised form
10 December 2015
Accepted 11 December 2015
Available online 7 January 2016

Keywords:
Bayesian Belief Network
Hierarchical generalized linear model
Fishery certification
Catch share management
Marine Stewardship Council

ABSTRACT

This paper describes how Bayesian Belief Networks (BBNs) were used to investigate how a management intervention affects multiple aspects of a fishery's performance. The ideas were developed in the context of a specific case study in which fishery performance was measured using the Marine Stewardship Council (MSC) certification scores, and the management intervention was whether the fishery is under catch share management (a form of rights based management) or not. A fishery's performance is scored against more than 30 indicators to obtain MSC certification. These indicators are grouped into three Principles that measure different aspects of sustainability. The effect of catch share management must be investigated in the light of other fisheries characteristics such as gear type and target species, which can also affect MSC scores. Statistical models can measure the effect of these characteristics on the scores for each individual indicator, but are not able to assess their effect across all of the Principles together at the same time. A BBN summarised and synthesized the results from each indicator's statistical model. It was possible using the BBN to (i) compare the probability of scoring highly on all three Principles, or subsets of indicators, for fisheries with different characteristics and catch share management strategies, (ii) identify whether a fishery that scores highly on all three Principles is more likely to be managed using catch shares and (iii) identify the characteristics and indicators that are most associated with obtaining high scores across all three Principles. The BBN was able to address a wide range of questions and provide a mechanism for integrating a suite of statistical models describing a complex dataset with multiple response variables of interest.

1. Introduction

Assessing how the performance of a fishery changes in response to management intervention is challenging. Fisheries performance is often assessed against multiple, and potentially conflicting, objectives that include desirable economic, ecological and social outcomes. Various attempts have been made to disentangle these objectives, including the development of suites of performance indicators that consider aspects of economic, ecological and social sustainability (e.g. Felthoven and Kasperski, 2013; Anderson et al., 2015) or measurement of the ecological and/or social and economic performance of catch share programs, (e.g. Essington, 2010; Clay et al., 2014). The challenge remains as to how to assess the overall impact of a management intervention across a suite of different indicators within a single coherent framework, particularly when the available data are not specifically collected with the intention of measuring the effects of the intervention of interest.

The effect of a management intervention on the performance of a fishery is further complicated by the dynamic environment in which fisheries management is conducted. Fishery management tools are typically implemented following a decision made by an individual fishery, possibly along with other accompanying decisions, rather than as part of an experiment or randomised control trial in which the management intervention is isolated from other potential changes. In addition, measuring fishery performance is data intensive and time consuming and so designed surveys, where the performance of a carefully selected set of fisheries is assessed, potentially both before and after an intervention, are often too expensive to implement. Instead, an intervention's success is often evaluated using fisheries performance data that have been collected routinely and not expressly for the purpose of evaluating the effects of a specific management intervention (e.g. Essington, 2010;

* Corresponding author. Present address: Department of Mathematics and Statistics, Whiteknights, PO Box 220, Reading RG66AX, UK.
E-mail address: fiona@fmunderwood.com (F.M. Underwood).

http://dx.doi.org/10.1016/j.fishres.2015.12.005
0165-7836/

Costello et al., 2008; Chu, 2008). The consequence of this is that differences in fisheries performance may depend on the effects of basic fishery characteristics, such as the target stock, the fishing gear and the fishing location, or other contemporaneous management interventions. Any analysis of the data must investigate these possible effects before attributing change to the management intervention of interest.

Finally, the effect of an intervention may differ depending on the fishery characteristics. For example the intervention may affect performance for some target stocks and not others. Furthermore, the effect of the intervention may vary across the different aspects of performance. A coherent framework must consider the effect of multiple, potentially interacting, causes on multiple outcomes.

These ideas are developed here in the context of a specific example. Parkes et al. (2016) describes a research question about the relationship between a fisheries management tool (catch shares) and the performance of fisheries under the ecological standard of the Marine Stewardship Council (MSC) fisheries certification program. An aim of both catch share management (a form of rights-based management) and MSC certification (an incentive program) is to make fisheries more sustainable. Sustainability is multi-faceted and the MSC has developed a suite of indicators that measure different aspects of fishery performance to assess fisheries for certification (MSC, 2013). There is interest in whether catch share management leads to improvements in the aspects of sustainability that are measured by the MSC standard Parkes et al. (2016).

To address this question, the MSC made available assessment scores and information about the characteristics of MSC-certified fisheries, such as gear type and target species. The MSC program, however, is not specifically interested in whether fisheries are managed using catch shares. The Environmental Defense Fund (EDF), an environmental NGO, provided a database of worldwide fisheries under catch share programs. From these two sources of information, it was possible to identify which of the MSC certified fisheries were managed using catch shares and the basic attributes of those catch share programs (Parkes et al. (2016)). As is often the case when measuring the effects of fishery management, we were using two data sources for a purpose they were not designed for. Nevertheless, we wanted to extract as much information as possible to try to answer the research question posed above. This paper describes the methodological challenges; the results are presented in Parkes et al. (2016),

The challenge was to use a statistically sound and evidence-based approach to investigate (1) whether MSC-certified fisheries managed with catch shares achieved higher scores than non-catch share managed MSC-certified fisheries at the levels both of individual performance indicators and composite scores and (2) whether MSC-certified fisheries with high scores (for either individual performance indicators or composite scores) were more likely to be managed under catch shares than not. Furthermore, there is interest in learning whether the effect of catch share management is modified by different fishery characteristics.

1.1. The challenge

The MSC dataset provided scores for 30 Performance Indicators, organised within a number of Components nested under three Principles that evaluate different aspects of the sustainability of a fishery. The score achieved at the Principle level is the average of the relevant Component scores, which are themselves the average of the relevant Performance Indicator scores. To become certified, a fishery must achieve passing scores at Indicator and Principle levels (MSC, 2013).

Fisheries are scored against the Performance Indicators, so any initial analysis should investigate the effect of catch share management on those scores. The dataset includes fisheries with different combinations of fishery characteristics, such as gear type and target species and these may themselves lead to differences in the scores of each Performance Indicator. The potential effects of these fisheries characteristics on each Performance Indicator must be accounted for before examining the effect of management and whether these characteristics modify the effects of management. One possible approach would consist of a separate statistical modelling exercise to assess the effect of these characteristics and catch share management on each Performance Indicator score. Similar analyzes for each Component and Principle score could provide additional insights. Although this might be useful, it would produce a large number of results that would be difficult to synthesize to make more general statements about the effects of catch share management on scores across the MSC standard as a whole (that is across Performance Indicators, Components and Principles) and for different fisheries characteristics.

Typically, (traditional) statistical models, for example regression modelling, investigate the relationship between multiple independent variables, such as fisheries characteristics and catch share management, and one response variable; in this case an individual Performance Indicator. These statistical models could potentially be extended to look across three response variables (the Principle Scores), but would struggle to look across 42 response variables (30 Performance Indicators, nine Component and three Principle scores).

1.2. The solution

Here, we describe the use of Bayesian Belief Networks (BBNs) (Pearl, 1985) to meet the challenge. A BBN provides a coherent framework that is able to capture the known relationships between Principles and Components, Components and Performance Indicators and the *a priori* unknown relationships between Performance Indicators and fisheries characteristics, including whether they are managed using catch shares. The BBN developed here drew together the results from statistical models describing the effects of catch shares and fisheries characteristics on the Performance Indicator scores. This made it possible to answer questions about all three Principles in relation to catch share management at the same time, as well as about individual Principles, Components and Performance Indicators, all of which can have a bearing on whether a fishery actually achieves certification.

The overall study aim was to use these data, which were originally collected for other purposes, to investigate how fishery performance, using a structured set of indicators, differed between fisheries using a management tool (catch share) and those not using this tool (non-catch share). We describe how the BBN was built, briefly illustrate how it was able to answer different types of questions about MSC certification scores and catch share management and discuss the appropriateness of this approach to this particular case study and more generally. More detailed results of this specific study are provided in Parkes et al. (2016).

2. Theory

BBNs, sometimes described as probabilistic expert systems, are simplified models that capture probabilistic relationships between variables (Cowell et al., 1999; Jensen, 2001). They have been applied to problems in natural resources management (Cain, 2001; McCann et al., 2006; Castelletti and Soncini-Sessa, 2007; Zorrilla et al., 2009) and risk assessments of fish and wildlife populations (Marcot et al., 2001; Pollino et al., 2007). Within fisheries, BBNs have been used to assess and compare management plans (Kuikka et al., 1999; Levontin et al., 2011), and evaluate factors affecting the