Fisheries Research 148 (2013) 18–26

Contents lists available at ScienceDirect

Fisheries Research

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

Linking physiological, population and socio-economic assessments of climate-change impacts on fisheries

Ana Norman-López [a,*], Éva Plagányi [b], Tim Skewes [b], Elvira Poloczanska [a], Darren Dennis [b], Mark Gibbs [b], Peter Bayliss [b]

[a] CSIRO Climate Adaptation Flagship, CMAR, PO Box 2583, Brisbane, QLD 4001, Australia
[b] CSIRO Wealth from Ocean Flagship, CMAR, PO Box 2583, Brisbane, QLD 4001, Australia

ARTICLE INFO

Article history:
Received 18 October 2011
Received in revised form 18 February 2012
Accepted 20 February 2012

Keywords:
Climate
Input–output analysis
Panulirus ornatus
Torres Strait
Risk assessment

ABSTRACT

Climate change is postulated to influence marine resources worldwide with consequent ramifications for the management of commercially important fisheries. There is a need to understand the likely impacts of climate change affecting the biology of fisheries at each of the different levels: (a) individual (reproductive potential, larval settlement, spatial distribution); (b) population (carrying capacity, productivity, spatial distribution); (c) multi-species (replacement of one fishery by another) and (d) ecosystem (dependent predator species, shifts in community composition). When addressing these problems it is important to integrate information across a range of dimensions pertaining to the resource and stakeholders, using a combination of biological, economic and social research elements. This is necessary for a better understanding of the likely changes to catches and in turn the possible socio-economic implications. We assessed the impact and likelihood of a range of plausible climate impacts on a number of lobster life history parameters, using the Torres Strait tropical rock lobster *Panulirus ornatus* as a case study. The hypothesised high risk effects of climate change were implemented through modifications to the lobster stock assessment model. Projected catches and an input–output model of the Australian economy were used to determine the flow-on effects of climate-change impacts affecting this lobster fishery. We highlight the potential of this combination of quantitative and qualitative approaches as a pragmatic first step to exploring climate-change impacts on a fishery and summarise implications for management. Our results suggest that there may be positive as well as negative consequences. Our integrated methodology is a step towards linking the interrelation between different variables and fishery productivity, and quantifying the resultant socio-economic effects to fishers, their communities and national economies.

1. Introduction

Fish populations respond to a variety of natural and anthropogenic pressures, which coupled with density-dependent processes result in changes to stock status and resultant management responses for targeted species. Climate change is an additional impact on top of existing pressures that will affect fish stocks in different ways. Studies have concentrated on the direct (growth, reproductive capacity, mortality, distribution, etc.) and indirect (structure of ecosystems) consequences of climate change on marine species, populations and fishery production. However, concurrent pressures from other stressors including fishing, pollution, ecological and socio-economic interactions can reduce the resilience of marine fish stocks and as such intensify the effects from climate change. A more holistic approach is to evaluate the likely effects from climate change together with other factors impacting marine systems (Hollowed et al., 2009). This could provide a more accurate representation of future changes in fishery productivity which in turn can be used to assess the expected socio-economic effects on dependent fishing sectors, and on regional and national economies (MacNeil et al., 2010).

We outline a methodology for linking and quantifying the biological and socio-economic implications of climate change on a fishery. The biological effects from climate change are considered with respect to individuals, populations and the ecosystem. Using a lobster stock assessment model these effects are integrated with other natural and anthropogenic effects already impacting the fishery. This model then projects future changes to catches that would allow the fishery to continue operating sustainably (Plagányi et al., 2009). The employment and income effects following changes to catches are then estimated for the dependent fishing sectors, the region and the national economy using an input–output model (Norman-López and Pascoe, 2011; Norman-López et al., 2011).

* Corresponding author.
E-mail address: ana.norman@csiro.au (A. Norman-López).

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doi:10.1016/j.fishres.2012.02.026

Rock lobsters may be particularly vulnerable to climate change given their apparent sensitivity to associated physical parameters such as temperature, winds, ENSO event frequency and ocean acidity (Caputi et al., 2010; Frusher et al., 2007). Given their dual role as a commercially highly valuable resource and their "keystone species" role in maintaining ecosystem structure (Barkai and Branch, 1988; Barkai and McQuaid, 1988; Barrett et al., 2009; Haley et al., 2011; Shears and Babcock, 2002; Ye et al., 2008), they are an important species to focus our understanding of possible climate-change effects, and appropriate management responses.

The Torres Strait tropical rock lobster (*Panulirus ornatus*) (TRL) was selected for our study because of the long time series of empirical information and relatively good understanding of lobster ecology (Pitcher et al., 1992; Ye et al., 2005). Further, this fishery is unusually complex: it overlaps the international border between Papua New Guinea and Australia and is exploited by two different sectors within Australia; indigenous inhabitants (Islanders hold traditional inhabitant boat – TIB licenses) and non-traditional fishers (non-Islanders operate as transferable vessel holders – TVH) (Fairhead and Hohnen, 2007). The strong dependency of local fishers on rock lobster is likely to further complicate the management of the resource under climate change.

The stated objectives for this fishery include maintaining the spawning stock at levels that meet or exceed the level required to produce the maximum sustainable yield, to optimise the value of the fishery and in accordance with the Torres Strait Treaty, to protect the traditional way of life and livelihood of traditional inhabitants, particularly in relation to their traditional fishing for TRL. The fishery is currently the most important fishery to Islanders and provides significant financial independence for Island communities in the region. More than 15% of employment in Islander communities is estimated to come directly from lobster fishing (Arthur, 2005). Tropical rock lobster is also a highly valuable fishery for non-Islanders, with this sector's numbers restricted to promote the socio-economic development and maintain the traditional lifestyle of Torres Strait Islanders. In 2008–2009, only 10 non-Islander vessels were operating in the fishery compared to 279 Islander vessels. Nevertheless, non-Islander vessels caught nearly 43% (99 t) of the total Australian catch (228 t) because they are larger, and apply more effort. In addition, unlike Islander vessels, non-Islander vessels supply most catches live obtaining a higher market price and hence revenue. Overall the total value of the fishery in 2008–2009 was estimated to be AU$7 million (Ward et al., 2009).

Climatic changes to sea surface temperatures, ocean acidification, sea level rise, cyclone intensity, rainfall, river flows and so forth, are expected to affect catches (Hobday et al., 2008). Changes in Torres Strait lobster catches will impact the fisheries' profitability, fishers' wages and employment. This in turn will change the fishers' expenditure/consumption on other industries' products produced within and outside the Torres Strait region. In addition, changes in catches will require the fishing industry to adjust its demand for fishing inputs (i.e., fuel, labour, repairs), and the supply of lobster products to intermediate (i.e., processors) and final demand sectors (i.e., restaurants) located in the Torres Strait region, other Australian regions and internationally. This will have subsequent socio-economic flow-on effects in terms of production, incomes and employment to other upstream and downstream industries.

In this paper, we assessed the plausible impact of climate change operating on a range of levels on the *P. ornatus* population, summarise the implications for management, and quantify the resultant socio-economic effects to fishers, their communities and national economies.

2. Methods

The possible biological and socio-economic effects of climate change on the *P. ornatus* fishery in Torres Strait were investigated in three steps. In the first step, we assessed the potential impact on several rock lobster biological response variables from changes in an array of climate change-related physical variables and ecological components. Potential impacts were then assigned to a "risk" category (high, medium or low) depending on the likelihood of the climate-related change and the size of the potential impact (or consequence) on the biological response variable. From this, two scenarios were outlined and their combined impacts on the lobster biological response variables were estimated; a high risk impact scenario and a combined high and medium risk impact scenario. The latter scenario was combined because the medium risk impacts are additional to the high risk impacts. In the second step, the hypothesised high risk and high plus medium risk scenarios of potential impacts were implemented as changes in rock lobster production through modifications to a lobster stock assessment model. Finally, in the third step, projected catches obtained from the lobster stock assessment model were incorporated to an input–output model of the Australian economy to determine the income and employment flow-on effects to the regional and national economy.

2.1. Step 1. Assessing risks of climate impacts on the rock lobster population

Our estimation of risk is similar to traditional risk assessment approaches, however, in this case, risk is "risk of impact", not "risk of negative impact", as we consider both detrimental and advantageous outcomes. Risk rankings for potential impacts on lobster biological variables from climate-change related changes in physical variables were formulated from the likelihood of the climate-related change and the consequence that the change has on the lobster biological response variable.

The likelihood and the projected changes to several physical variables in Torres Strait due to climate change were obtained from the literature (Table 1). The projections were considered for short-term to 2030 as this has higher management relevance than longer term projections. Projections of global warming were considered only for the mid–high range greenhouse gas emission scenario (A1B) (IPCC, 2007) as there is little deviation by 2030 among different emission scenarios. Marine ecosystems will also be indirectly impacted through flow-on effects from changes to primary productivity and disruption to food webs (Poloczanska et al., 2007), and we integrated these impacts where possible. Likelihood scores of the physical parameter changing were assigned based on confidence ratings by experts in the field (Poloczanska et al., 2007); >70% likelihood was considered as high, <30% low and intermediate values medium (Table 1).

The potential impacts of changes to physical variables and related changes to three critical habitats (deep epibenthic communities, coral reefs and seagrass beds) on a range of life history variables (growth, mortality, movement, distribution and reproduction) were assessed separately for three rock lobster life history stages (larvae, juvenile and adult) in Torres Strait. Each potential impact was described and quantified to the fullest extent possible using information from literature reviews, unpublished experimental studies and expert consultation. Considerable uncertainty exists for most combinations of physical and (lobster) biological variables. We took the approach, in this case, of using all available information to outline likely potential impacts for use in the subsequent stages of the analysis. Where no information was available, that combination of physical and biological variables was