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Strengthening the resilience of small-scale fisheries: A modeling approach to explore the use of in-shore pelagic resources in Melanesia

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A B S T R A C T

Small-scale fisheries play a critical role in both poverty alleviation and food security. A large proportion of the world fish stocks are, however, getting fully or over-exploited. In this article we address these issues in the context of the small-scale fisheries of the Solomon Islands. The paper explores the extent to which in-shore Fish Aggregating Devices (FADs) can help increasing the resilience of the small scale fishery system and reconciling social, economic and ecological priorities. Based on the concept of 'time of crisis' developed recently in the viability literature, we propose to calculate a resilience index through a dynamic stochastic model calibrated by ethnological observations. The resilience index calculation reveals two major findings: (i) the resilience of the small scale fishery system is currently nonexistent and (ii) the introduction of FADs can improve it. The effects of the FADs' implementation are then discussed in the light of a socio-economic perspective. Such results bring new insights into the question of the future of the small scale fishery sector, especially in relation to the local economy evolution from a barter dominance to a cash oriented economy. At the same time, the current subsistence fisheries seems more resilient in general due to a distributive effects which ease the 'race for fish behaviors'. Finally, our analysis reveals that while the FADs implementation stands as a short and mid-term answer, demographic drivers are important and other alternatives will need to be considered if the overall viability of the system is to be maintained in the longer-term.

1. Introduction

The sustainable exploitation of ecosystems and the conservation of biodiversity are two of the growing challenges of this century, along with the global eradication of poverty (Hall et al., 2013). Fishery, as a typical system based on the exploitation of renewable resources, is very illustrative of such a challenge. Three quarters of the world fish stocks are estimated to be fully or over-exploited (Garcia and Grainger, 2005; FAO, 2012), and 95% of the people depending on these fisheries are small-scale operators living close or sometimes below the poverty line in low and middle income countries (Heck et al., 2007; Béné et al., 2007; Mills et al., 2011). Although poverty in small-scale fishing communities is not explained only by the status of the resources (Yari, 2003/04; Béné and Friend, 2011), the link between resources and fishers' well-being is important.

Fisheries are also recognized to be a critical source of "rich food for the poor" (Kawarazuka and Béné, 2010; Béné et al., 2007; Allison, 2011). Both producers (small-scale fishers) and poor consumers in rural and increasingly in urban areas, depend on fish as a critical source of animal protein, micro-nutrient, vitamins and beneficial fats (Kawarazuka and Béné, 2010; High Level Panel of Experts, 2014). In this context, improving management of the world's fish stocks in such a way that available resources can better contribute to both poverty reduction and food and nutritional security in a sustainable manner is a priority (Andrew et al., 2007; Allison, 2011). Food security, poverty alleviation and resource conservation should therefore be the three main and inter-related objectives of fisheries management in the developing world. Yet identifying strategies which promote these three objectives remains challenging. This challenge is in many places further compounded by factors such as encroachment of markets, rapid

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population growth, increased demand for fish, and environmental change and degradation (High Level Panel of Experts, 2014).

Our objective is to explore these issues of inter-connection between natural resource conservation and development in the case of fisheries; and we propose to use the small-scale fisheries in the Solomon Islands as our main 'ground level laboratory'. For Solomon Islands' communities, marine resources constitute a unique and critical pool of available high-quality protein and an important source of household cash. However, like many countries in the Pacific region, coral reefs around Solomon Islands exhibit many signs of localized depletion of finfish stocks (Green et al., 2006; Brewer et al., 2009). A critical question therefore is: to what extent and under which conditions can these marine resources continue to fulfil their socio-economic functions (cash, livelihood and food provision), and at the same time be exploited in a manner that does not threaten their current or future ecological capacity? To address this question we developed a novel approach where we combine elements of viability theory with aspect of resilience, and use a bio-economic model designed and calibrated with local data to explore the system dynamics.

Viability (or viable control) approach (Aubin, 2009) is a dynamic system-based approach that has now been recognized as an insightful modeling framework in relation to natural resource management (Cury et al., 2005; Eisenack et al., 2006; Doyen and DeLara, 2010), especially in fisheries -see, e.g., Béné et al. (2001); Doyen and Béné (2003); Martinet and Doyen (2007); Bene and Doyen (2008). Under this viability approach the objective is not to identify optimal or steady state paths for the co-dynamics of resources and their exploitation, but rather to identify desirable combinations of states and associated controls that keep the system's viability conditions satisfied.[1] In our Solomon Islands' case-study, these viability conditions relate to marine resource conservation, food security and poverty alleviation. When considered together, these constraints delimit a multi-dimensional space called the 'viability domain'. In this specific context the aim of the viability approach will be to analyse the compatibility between the dynamics of that system and the state constraints, and to determine the set of controls (or decisions) that will maintain the system's trajectories within this viability domain.

The concept of resilience will then be used to further explore the behaviour of the system around the boundaries of this viability domain. Many definitions of resilience have been proposed in different disciplines -see Manyena (2006); Bahadur et al. (2010) for reviews of these definitions. Most definitions share in common the basic idea that a resilient system is able to continue functioning effectively even after a shock. Quantifying or measuring this ability is however methodologically difficult (Armitage et al., 2012; Frankenberger and Nelson, 2013; Béné et al., 2012). In our case, we follow Béné et al. (2001) and Martin (2005) who, in a dynamic context, propose to link resilience to the concept of 'time of crisis'. The 'time of crisis' is the time it takes for a dynamic system to come back into its viability domain, following a shock. The more resilient a system is, the shorter the time of crisis will be. This approach is in fact relatively close to some of the earlier 'engineering' definitions of resilience as proposed by, e.g. Holling (1973) who defined resilience as the "ability of a system to bounce back or return to equilibrium following disturbance". In our case these disturbances will be considered by introducing stochastic elements in both the ecological and human dynamics of the system. The true novelty of the approach, however, comes from the fact that so far (to the best of our knowledge) linking viability to resilience and using the mathematical concept of time of crisis as a way to quantify the system's resilience in an empirical case-study has never been tried.[2]

2. The Solomon Islands' small scale fishery

The Solomon Islands' archipelago presents ecological and socio-economical characteristics that are relatively illustrative of the Melanesian context. On an ecological perspective, the Solomon Islands are situated within the Coral Triangle (see Fig. 1) and as such display one of the highest levels of marine bio-diversity in the world, with astonishing levels of primary productivity. The local artisanal fishers exploit diverse coral reef and pelagic species. The principal families amongst the reef resources include Serranidae (sea basses and groupers), Lutjanidae (snappers), Lethrinidae (emperors), Acanthuridae (surgeonfishes, tangs, unicornfishes) and Scaridae (parrotfishes). The pelagic catches are dominated by the skipjack tuna (*Katsuwonus pelamis*). Once landed, reef and pelagic fish are either consumed by fishers and their families, or sold locally (Sulu et al., 2000). Other exploited products include sea-cucumber, trochus, and shark fins. Those, however, will not be considered in this paper as their influence on the system is minimal at the present time: the shark fin market has not (yet) fully developed in Solomon Islands (compared to other places in the Pacific), the sea-cucumber fishery has been closed since 2005 due to strong evidence of overfishing (Ramofafia, 2004) and the trochus fishery has never really recovered from overexploitation 200 years ago and represents only a negligible part of landings and fisher cash (Foale, 1998, 2008). Our work will therefore focus on the reef fish and skipjack tuna resources.

From a livelihood perspective, households in Solomon Islands engage in fishing for two main reasons; subsistence (self-consumption of fish to complement the home garden and contribute directly to food security) and cash-income to purchase other commodities: foods (e.g. rice) and essential goods (clothes, pieces of furniture, kitchen utensils, etc.), (Kile, 2000). In fact the country is characterized by one of the highest fish consumption rates of the region (35 kg/person/year (Bell et al., 2009)), but also the highest demographic growth rate in the Pacific region (between 2.3 and 2.8% (CIA, 2001)) and the lowest Human Development Index of the region (143/186). In those circumstances, the small-scale fishery represents the only economic opportunity for many (rural) households and stands as a keystone sector.

In Solomon Islands all fishers -essentially male head of rural households- are engaged in reef fishing, and to a lesser extent outside the reef in inshore sea fishing. These fishers split their fishing time (around 15 h per week) between the two fisheries (Aswani, 2002, 1998), but with a marked preference for the reef fishery. The limited number of outboard engines and their relatively high operating costs also reduce considerably the number of local fishers who can access the tuna resource on a regular basis. As a result, a typical fisher would be mainly involved in coral reef fishery, with approximately only 10% of his fishing time spent outside the reef targeting the tuna resource (Aswani, 2002, 1998). The two types of resources, coral and pelagic, imply different

[1] From an ecological viewpoint, the so-called population viability analysis (PVA) (Morris and Doak, 2002) is remarkably close to this viability approach as it focuses on extinction probability in an uncertain (stochastic) environment. The Tolerable Windows Approach (TWA) proposes a similar framework on climatic change issues (Bruckner et al., 1999).

[2] The work of Duer-Balkind et al. (2013) addresses the conciliation between sociological drivers and ecological drivers under a quantitative approach of resilience. Although they do not take into account the economical constraints that drives the fishing efforts. Such economical constraints can be actually considered through the socio-economic viability constraints.