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Conservation and resource management in small tropical islands: Trade-offs between planning unit size, data redundancy and data loss

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ABSTRACT

Resource management and conservation require the definition of planning units (PUs), i.e., the spatial domain where management decisions are applied. PUs are either pre-established in size and shape following management constraints or are data driven (DDPUs) by overlay of multidisciplinary data layers. The trade-offs between these two approaches have not been investigated previously for small tropical islands and their characteristics. Here, we use resource density, fishing pressure and susceptibility to mortality for a giant clam fishery in a small French Polynesia atoll to discuss the suitability and impact of the two approaches in conservation management. Aggregation to pre-established PU grids highly affected data even for PU as small as 2500 m^2, with higher loss of spatial information for density and fishing effort. By contrast, DDPU rendered well small scale patterns of interest but reduced redundancy. Our results stress the importance of considering the initial patterns of data in the definition of planning units, and we suggest a 3 steps process to identify adequate trade-offs between PU size, PU redundancy and data loss to properly draw practical recommendations for small islands.

1. Introduction

Spatially explicit conservation plans are useful decision support tools for managers (Pelletier and Mahévas, 2005). In particular, these plans require the definition of a network of spatial planning units (PUs). Once the network is established, relevant properties are considered homogenous inside each PU, and they may be, individually or as clusters, the object of specific management actions (Moilanen et al., 2009). Their shape can be regular (square or polygonal) or irregular if they follow administrative and environmental boundaries and units of ownership or tenure (e.g., Pressey and Nicholls, 1989; Hermoso and Kennard, 2012; Ma et al., 2012a).

The use of PUs extended during the past decade with the development of spatially explicit models. These models benefit, for example, systematic conservation planning (Ball et al., 2009; Moilanen et al., 2009; Deas et al., 2014), population, and fishery studies (Pelletier and Mahévas, 2005), and usually combine biological and sociocultural data (Léopold et al., 2014). Often, the shape and size of PUs are defined according to planning objectives and management capacities (e.g., surveillance logistical capacities, (Moilanen et al., 2009)). However, the consequences of such *ad hoc* choices remain unclear in terms of data and model quality as discussed for freshwater systems by Hermoso and Kennard (2012). Indeed, relevant spatial patterns visible in initial data but smaller than PU size may be missed when data is degraded to fit the pre-established size and shape of PUs. Conversely, when PUs are small relative to the initial data variation, some configurations may be over-represented in a network. A predefined, arbitrary, PU network may thus notably influence models output and management decisions (Pressey and Logan, 1998; Ferrier and Wintle, 2009; Nhancale and Smith, 2011). When the grain size of important data (e.g., resource stocks, fishing locations) is small like for Pacific island fisheries (Hamel and Andréfouët, 2010; Hamel et al., 2013; Léopold et al., 2014), it seems that defining a PU network according to data

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accuracy and spatial pattern would be a more sensible approach than defining PUs on the basis of management possibilities only.

To understand how arbitrary PUs may alter management decision in the context of tropical island small fisheries, we compare the influence of geometry and design of PUs on data loss and redundancy. Data redundancy is defined here as the proportion of PUs sharing the same combination of data values. For this, we used data layers that are currently judged critical for the sustainability of a small giant clam fishery in a remote atoll of French Polynesia to 1) assess how aggregation for different PU sizes affect data values and spatial patterns; 2) compare redundancy for two PU designs: a systematic grid and a data driven network (DDPU). Trade-offs between PU grid size, PU redundancy and data loss is examined to draw recommendations for conservation and management of small islands.

2. Methods

2.1. Study sites

French Polynesia is located in the Central Pacific Ocean and includes 118 islands distributed in five archipelagos. This study focuses on Tatakoto, an isolated and semi-closed atoll located in the eastern Tuamotu Archipelago (Fig. 1). Very high stock and densities were reported for the small giant clam *Tridacna maxima* in this lagoon in 2004 (up to 544 ind m^{-2}; Gilbert et al., 2005) although the stock is not even, with patchy densities found throughout the lagoon depending on habitat types, depth and location (Gilbert et al., 2006). Highest densities and stocks were found on the patch reefs of the eastern lagoon (Fig. 2). Patch reef size is typically on the order of few tens of meters (see Fig. 6 in Gilbert et al., 2006).

Only 287 inhabitants live on Tatakoto, all aggregated in the western end of the atoll (Tumukuru village). However, *T. maxima* stock is subjected to a significant exploitation with up to 20 tons of flesh sent annually toward the French Polynesia main island, Tahiti (in 2007, DRMM data). Less significant, but growing, exploitation also includes the temporary collection of live specimen for the aquarium trade. Fishing grounds are known to be different depending on the type of fisher activity, with professional-like fishers traveling greater distances than others (Gilbert et al., 2007).

The significant extraction of giant clam and the fairly small lagoon size (17.7 km^2), promoted the decision in 2004 by the Service de la Pêche (Fishery Services of French Polynesia) and in agreement with the local population, to create a 0.5 km^2 No Take Area (NTA) in the eastern sector of the lagoon (Gilbert et al., 2005). However, this conservation and management action was offset by a massive mortality that likely occurred in 2009, probably triggered by unusual weather conditions and temperature (Andréfouët et al., 2013, Andréfouët et al., 2015). The entire lagoon was affected but Andréfouët et al. (2013) reported higher mortality rates in the NTA compared to other areas. This shallow enclosed part of the lagoon with poor water renewal could be more vulnerable to warm periods of low wind and low swell (Andréfouët et al., 2015).

The combination of spatially structured stock per habitats, differential susceptibility to mass mortality from west to east, and differential level of fishing pressure according to fisher range of behavior suggests that the lagoon is likely a tight mosaic of small areas with different exposure to fishing and mortality risk. As such, Tatakoto lagoon represents well the situation that occur in small islands where subsistence and fishing put resources at risk, and where climate-induced threats are an additional complication to design spatially explicit management plans (Bell et al., 2011).

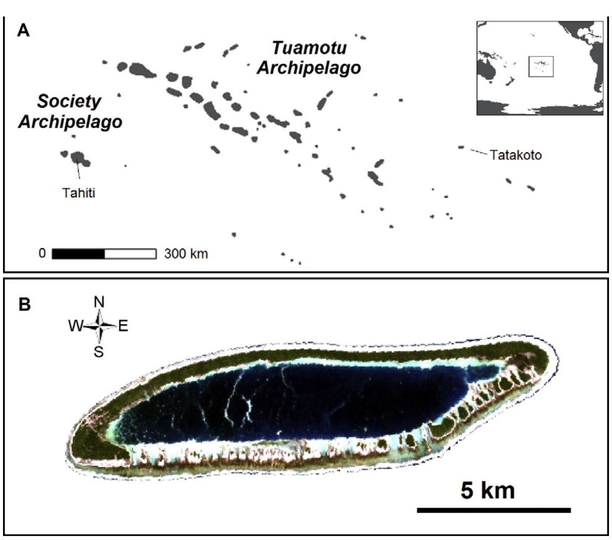

Fig. 1. A: Location map of Tatakoto atoll in French Polynesia; and B: satellite image of Tatakoto atoll (Quickbird imagery, 2.4 m spatial resolution).

2.2. Spatial data acquisition

Resource status was characterized by measuring *in situ* giant clam density at habitat scale (63 stations) and extrapolating to the entire lagoon using habitat maps. Densities were measured in 2004 and reported by Gilbert et al. (2006). The extensive survey implemented at Tatakoto atoll and methodological baselines are described by Gilbert et al. (2006).

Susceptibility to massive mortality was considered as the main driver of giant clam density in the past decade at Tatakoto (Andréfouët et al., 2013). Spatial data on susceptibility to mass mortality was directly issued from Andréfouët et al. (2013), who reported 91% mortality inside the enclosed shallow NTA and 59% outside, both values are an order of magnitude higher compared to other isolated islands (Apte and Dutta, 2010). Vulnerability is thus expressed as a percentage of change of density between 2004 and 2012.

We characterized the spatial distribution of fishing efforts by conducting interviews of local inhabitants in July and October 2013. Two interviews were specifically dedicated to the behavior of the most active fishers known from the local authorities. Then, seventeen interviews targeted randomly chosen households (one person interviewed by household) to map the range of fishing behavior and the associated range of fishing pressure. Interviewed people ranged from 15 to 80 years old and represented 7% of the population, but their answers were usually relevant to their entire household (spouse, children and parents), and likely represented well the population. During each interview, the questions aimed to clarify 1) the targeted size of fished giant clam; 2) depth of fishing; 3) fishing gears and tools used to collect, extract flesh from shells, and clean up giant clam flesh; 4) frequency of fishing trips; 5) catch weight; and 6) destination for catch (export to Tahiti, local consumption, etc.). For each of these 6 questions, a semi-quantitative index was defined using the key legend given in Table 1, and was attributed to each surveyed household. Euclidean distances and classification tree (group average method) were then established using Primer® 6.1.10 to provide a typology of fisher behavior.

Spatial maps of fishing effort were issued for each surveyed fisher. For fishers that swim, the fishing ground was defined arbitrary as the 100-m buffer around the mooring points, as fishers usually do not swim long distances without moving their boat (personal observation). Maps of fishing ground were compiled using the GIS Esri® ArcMap 10.1 software for each type of fishers found in the cluster. Spatial repartition of fishing effort was finally