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Abstract :

This paper investigates the dynamics of institutional development and co-management performance in small-scale fisheries. The study covers different contexts and spatial and temporal scales, for nine case studies in the South Pacific. In these cases, new co-management institutions were intentionally set up from 2008 to 2016 through fishery policy intervention to address over-exploitation problems of sea cucumber resources. This was carried out in a process of adaptive experimentation, based on a collaborative and problem-solving approach to governance, and a context-based vision of sustainability issues. In order to quantitatively and empirically assess change in governance within and between cases, a multidimensional analytical framework of governance performance is developed. A set of governance performance criteria is defined and the criteria are scored using data from an institutional diagnosis of the cases, throughout the research period. Ten out of eleven criteria were positively impacted by the co-management interventions. Three institutional development trajectories can be identified for the fishery co-management building process, involving a range of gradual and abrupt changes. Consolidation of the institutional changes achieved by the interventions is required to successfully develop the resilience of the fishing systems to multiple stresses. This empirical study provides a methodology for systematically assessing institutional dynamics in fisheries, and in particular the crafting and sustaining of co-management regimes in small-scale fisheries. The approach could potentially be applied to other complex social-ecological systems.

Highlights

► Our adaptive experimentation projects allow assessing fishery policy interventions. ► Fishery co-management development is highly dynamic over several years. ► Three institutional contexts are analyzed according to multiple governance criteria. ► Governance performance fits within three specific temporal trajectory patterns. ► Consolidation of institutional changes is needed to build robust governance systems.

Keywords : Action research, Adaptive experimentation, Governance, Institutional change, Small-scale fisheries, Social learning

1. Introduction

Small-scale fisheries are characterized by a high level of local diversity and by vulnerabilities that vary across both ecological and human dimensions. Management of these social-ecological systems thus requires a holistic approach as well as contextualization of sustainability issues (Berkes and Folke 1998; Berkes et al., 2001; Kooiman and Bavinck 2005; Pomeroy 2016). This article focuses on the governance of small-scale fisheries – the social interactions that determine the institution-building process, the resulting formal and informal rules, and actor networks that influence how management initiatives are imagined, designed, and implemented (Kooiman 2003). Governance regimes and actions critically influence the dynamics of resource use, transforming resource sustainability issues into social and political affairs (Chauveau and Jul-Larsen 2000; Béné 2003; Fabinyi et al., 2015). The characteristics of governance regimes determine such aspects as individual incentives for engaging or not in decision-making and constraining cooperation, the likelihood and time horizon of expected impacts of related decisions, transaction costs associated with maintaining cooperative agreements, and the distribution of benefits and costs of their implementation (Hanna 2014).

Given the multiple social interplays within fishery systems, the dynamic nature of interactions between governance regimes and the fisheries themselves, and the variability of external market and environmental drivers of change, the question of adaptation of governance regimes to resource and harvesting dynamics has been a fundamental issue for practitioners and researchers working towards the sustainable development of fisheries (Dietz et al. 2003). Because fisheries may be subject to uncertain and un-predictable stresses of different origins and intensity, governance regimes may need to adjust through adaptations and/or transformations, to enable socially and environmentally acceptable management decisions in a timely manner (Folke 2006; Young 2010).

Co-management and learning have been proposed as effective processes for enabling increased adaptive capacity for fisheries governance (Folke et al. 2005; Mahon et al. 2005; Armitage et al. 2008; Seijo and Salas 2014). Fisheries co-management is widely regarded as the most equitable and rational governance regime to address overexploitation problems in fisheries (Sen and Nielsen 1996; Jentoft 2003; Berkes 2010; Guttiérez et al. 2011). On the one hand, the greater effectiveness of co-management regimes over centralized or locally-based management regimes is linked to their positive effects on the legitimacy of decisions and, consequently, on individual incentives for cooperation and transaction costs (Baland and Platteau 1996; Jentoft 2000; Hanna 2003). On the other hand, co-management effectively develops individual and collective learning capacities through action (Carlsson and Berkes 2005; Armitage et al., 2008).

Such a learning process is at the heart of emerging collaborative and transdisciplinary research methods on fisheries, which have been promoting a paradigm shift for the last decade (Johnson et al., 2013; Gasalla and de Castro 2016). By encouraging short-term actions to better address the real-world problems of fisheries, promoters of these methods aim to achieve better coordination and formalization of the participation of scientists, local actors, and public managers and policy makers in the process of knowledge production (Garcia and Charles 2007). The paradox created by such collaborative research innovations, however, is that they tend to focus on knowledge production and learning, and changes in governance arrangements, within

the local social arena (e.g., Armitage et al., 2017). They do not usually address the question of multi-level governance change, which necessarily involve interactions between local and government authority levels and actors. This weakens their contribution to practical implementation of co-management in fisheries.

The purpose of this paper is to address this limitation and thus contribute to the study and the design of effective fishery co-management, with a focus on small-scale fisheries. To do so, we examined a set of research initiatives which were developed to address management issues in multiple small-scale fisheries in the South Pacific. In order to assess the impacts of these initiatives, we defined a conceptual model of institutional development in a small-scale fishery, and its response to public policy changes through action-research driven interventions. Based on this conceptual model, we structured a multi-criteria evaluation framework which enabled us to assess the dynamics of co-management performance in response to interventions in different fisheries contexts, and at different spatial and temporal scales. This evaluation framework was then used to assess nine case studies in the South Pacific, where institutions were intentionally set up to address problems of over-exploitation of coastal fisheries resources as part of adaptive experimentations. We finally examined how those experimentations and case study contingencies directly and/or indirectly affected institutional innovation and institutional performance in the fisheries studied.

2. Theoretical background: linking institutional innovation, co-management and learning in small-scale fisheries

2.1. Diagnosing institutional processes

The research presented in this paper is based on the theoretical perspective of new institutional economics regarding collective action and the management of common-pool resources. Endogenous or co-constructed cooperative solutions to manage these resources take the form of institutions, defined as sets of rules, norms, beliefs, roles, laws and mechanisms that constrain and facilitate human organization and actions (Feeny et al., 1990; Ostrom 1990). Theoretical and empirical research on the management of common-pool resources has dedicated much of its effort to the effectiveness of alternative, cooperative institutional designs and the factors encouraging or discouraging actors to organize collectively, to craft and transform institutions, and to comply with established rules (Ostrom et al. 1999; Agrawal and Goyal 2001; Dietz et al. 2003; Ostrom et al. 2002; Berkes 2005; Ostrom 2009). The well-known design principles of Ostrom (1990), reviewed by Cox et al. (2010) provide a synthesis of this knowledge for the purpose of answering practical management problems - including the small-scale fishery sustainability challenge that has been a major and recurrent concern worldwide.

Because of the large number and complexity of the factors involved in the success and failure of governance institutions (Agrawal 2001), Ostrom (2007) proposed a systemic diagnosis approach. This approach is based on the selection and documentation of certain variables that characterize the status of system components (resource, users and governance regime), as well as external drivers at different scales. This has enabled the study of both the interactions between variables that shape institutional change, and the multiple, dynamic causal mechanisms

influencing governance performance and fishery sustainability (Basurto et al. 2013; Cinner et al. 2013).

By contrast with such a systemic diagnosis, Young's (2002) approach to the evaluation of institutional design follows an actor-oriented, interactionist logic. This is consistent with empirical evidence showing that institutional change both results from and affects the social arena depending on the political and historical context. Specifically, following Young (2008b), the institutional diagnosis approach relies on a multi-scale analysis of the social arena using four main questions: What are the concrete problems regarding between-user and resource-user interactions that need to be solved? What is the socio-political context of these interactions? What are the relationships between the actors involved (or to be involved)? What are the current and common practices regarding institutional change? Importantly this approach specifically accounts for the different, legitimate authority levels and for multi-level governance interactions. Below, we examine how such an institutional diagnosis can be used to assess the impacts of interventions aimed at adapting fishery co-management in practical case studies.

2.2. Adaptive experimentation and institutional change

In dynamic social-ecological systems subject to complex and uncertain influences – as is the case with small-scale fisheries – the effectiveness of institutions with respect to management outcomes is inseparable from the institutional building process itself. The latter invariably involves social learning (Underal 2008), which is strengthened by interactive knowledge creation typical of adaptive management approaches and, consequently, by adaptive experimentation of co-management (Armitage et al., 2008; Dutra et al., 2015). Adaptive experimentation may in fact be seen as a context-specific research method for understanding causal interactions in small-scale social-ecological systems that are strongly impacted by human activities (Cook et al., 2004). In the present case, it constitutes a particular mode of participatory research based on collaborative, adaptive decision-making and learning-by-doing processes. This is consistent with the knowledge-action perspective on the nature and role of institutions in managing environmental affairs (e.g., Blaikie et al., 1997; Young 2008a). It also enables the development of an institutional diagnosis approach that aims at characterizing the social arena and reflecting and acting on the factors of institutional change "from inside the systems".

In such adaptive experimentations, researchers interact with other stakeholders and deliberately contribute to institutional change (Bardhan and Ray 2008). Recognizing that their individual skills, experience, attitude, beliefs, and values likely influence any participatory research project (e.g., Neef and Neubert 2011), their non-neutral role in the institutional process may then take at least two directions. On the one hand, researchers can play the role of "social bridges" at the interface of different categories of actors and help create a suitable context for the development of social capital (e.g., Folke et al. 2005). On the other hand, by getting closer to concrete social problems, they may contribute more effectively to the production of sound knowledge for institutional design, including public policies (Young 2008b).

Despite its practical and analytical potential, adaptive experimentation is rarely used in terms of governance issues related to social-ecological systems and to small-scale fisheries in particular (e.g., Perry et al., 1999; Tolentino et al., 2015). Adaptive experimentation creates an

opportunity for informed discussion, self-reflection, negotiation and expression of conflicts. By clarifying uncertainties as well as the expected and observed benefits and risks, this collaborative process aims to strengthen individual and collective learning and to create incentives to engage in collective arrangements that constrain current uses (Wilson 2003; Keen and Mahanty 2006).

2.3. A conceptual causal model for institutional change in common-pool resource management

To identify the impacts of an experimental intervention on institutions for common-pool resource management and on their effectiveness, a causal model of institutional change is required that captures key social-ecological processes in specific contexts. Stern et al. (2002, p. 453) defined a model of the impacts of interventions on institutional change based on four interacting factor categories: interventions, contingencies, mediators, and outcomes (Figure 1). Interventions are deliberate, influential actions derived from public policy and other government-supported institutional arrangements and legal frameworks. They therefore differ from participatory projects carried out at the community level, e.g. by non-governmental or research organizations (e.g., Wiber et al., 2009). Contingencies, or moderator variables, are factors outside the practical control of the authorities conducting interventions. They include external drivers (e.g., global market dynamics, large-scale environmental stresses) and internal context-dependent factors linked to the resource and user characteristics of the fishery system. Mediators, or intervening variables, may be affected by interventions and/or subject to contingencies. They include crafted instruments (e.g., enforcement and action capacities, knowledge production for understanding systemic linkages, legal framework) and social interactions (e.g., social learning, actors' interests) that drive governance outcomes. Outcomes are end results reached consequently to the effects of mediators on the fishery system. They include social (e.g., actors' behaviour), economic (e.g., catch levels and economic returns), and biological (e.g., resource abundance) factors that interact with mediators through feedback processes.

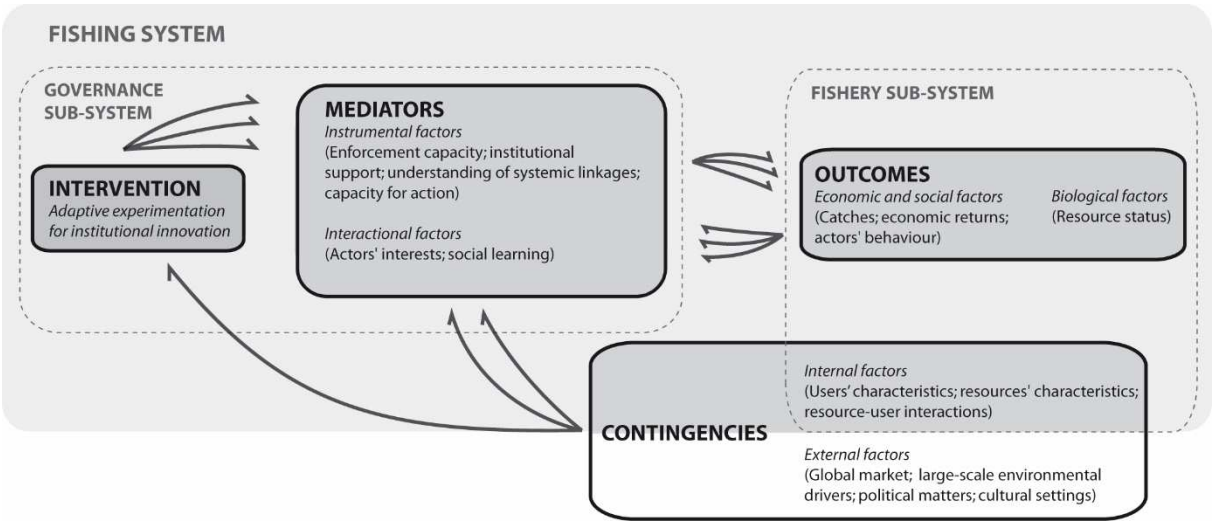

Figure 1. Conceptual causal model of the impacts of an intervention on the fishing socio-ecological system through adaptive experimentation (modified from Stern et al., 2002). Arrows represent the

causal relationships within the fishing system, which is composed of a fishery and a governance sub-system, as well as external drivers of change.

While emphasizing the legitimate and essential role of public authorities in governance (Pomeroy 2003; Jentoft et al., 2005), the model specifically takes into account the role of often conflicting negotiation interactions between government administrations, such as Fisheries Departments, and users. Such relationships occur through mediators and internal contingencies and are inherent to common-pool resource co-management (Singleton 2000). This conceptual model can be used to analyze how, and under which critical contingency conditions, policy intervention can successfully affect key intervening variables to achieve target outcomes. It thus offers a conceptual framework that is relevant to the particular case of experimental interventions in small-scale fisheries.

3. Material and methods

This causal conceptual model was applied to the analysis of adaptive, experimental interventions in small-scale fisheries of Vanuatu and New Caledonia (South Pacific). Here, we provide background information on the contexts for these interventions, and present the method used to assess the impacts of the interventions in the selected case studies.

3.1. Research site selection

In South Pacific island countries, social organization is traditionally based on communalism and reciprocity relationships though cooperation, although this has widely been transformed by economic, technological, and political change for the last five decades (Ward and Kingdon 1995). Such an organization has favored the emergence of small-scale (~1-10 km) reef fisheries management initiatives, governed by traditional local authorities. These community-based fishery management regimes impose specific restrictions on species harvested, and on periods, methods and/or areas of harvest at the local level, based on biological and social motivations, which are persistent manifestations of customary maritime tenure (Foale et al., 2011).

Despite occasional controversies (e.g., Wagner and Talatai 2007), social organization in the South Pacific a priori offers appropriate conditions for collectively defined, spatial fishery management regimes such as territorial use rights, and the hybridization of community and government levels of governance (Ruddle et al., 1992; Adams 1998; Ruddle 1998; Agrawal and Gibson 1999; Johannes 2002; Foale and Manele 2004; Aswani 2005; Berkes 2006; Cinner and Aswani 2007; White 2007; McClanahan et al., 2009).

In Vanuatu, a small island country, independent since 1980, coastal communities have constitutional ownership rights over the reef resources adjacent to their land. They therefore own both the legal and traditional legitimate authority to implement local fishing regulations within their marine territory, which interacts with the governmental fisheries management authorities (Johannes 1998; Léopold et al., 2013a). By contrast, in New Caledonia, a small French territory with autonomous government, reef fisheries are maintained under open access by the public authorities at the provincial level (David et al., 2010). In practice, however,

customary marine tenure effectively and informally governs reef fishing practices at the local level, although it lacks legal support (e.g., Guillemot et al., 2009; Léopold et al., 2014).

Legal pluralism, inherited from the socio-cultural context and postcolonial history, constitutes a strong contingency for reef fishery governance as well as an opportunity to implement co-management institutions in both contexts (Bavinck et al., 2015). The administrative and political structures governing the fishery sector in both countries are of low complexity, due to the small size of island populations (i.e., < 300,000 inhabitants), which facilitated our research approach.

Small-scale commercial tropical sea cucumber fisheries were used as reference fisheries because they met two conditions facilitating adaptive experimentation. On the one hand, targeted sea cucumbers are sedentary species that live in shallow coastal areas. They are easily collected on reefs at low tide and by free-diving fishers down to 15-m depths. Such ecological characteristics make spatial biological assessment and management (e.g., through total allowable catches (TAC)) appropriate for these resources (Perry et al., 1999; Castilla and Defeo 2001). On the other hand, sea cucumbers are highly vulnerable to fishing, for biological, ecological, and economic reasons (Purcell 2010). Demand for dried sea cucumbers (called "beche-de-mer") has markedly risen on Asian markets since the 1990s, which quadrupled the average export price of these products in the Indo-Pacific zone (>US$ 40 per kg of beche-de-mer products in 2013, Supplementary material). In poorly effective fishery governance regimes, the commercial exploitation of sea cucumber resources has thus been largely driven by highly attractive prices. Fishing pressure increased opportunistically and very sharply, and generated significant, undesirable socio-economic changes (Kaplan-Hallam 2017). In most tropical countries, sea cucumber catches have typically followed a boom and bust trajectory, characterized by rapid development and predictable collapse after a few years (Anderson et al., 2010).

The sharp decline in sea cucumber catches and exports in most South Pacific islands has prompted governments and communities to respond at national or local levels with an increasing use of moratoria (Kinch et al., 2008). In Vanuatu, a five-year moratorium was declared in 2008 following the collapse of the fishery. In New Caledonia, sea cucumber fisheries account for a minor part of economic activity in rural communities, resulting in less severe, although increasing overexploitation. Unsustainable harvest levels affected high-value species in the 2000s despite the introduction of minimum catch sizes (Purcell et al., 2009). Because it was observed by both rural communities and governments at the regional level, this crisis context created a window of opportunity for fishery policy intervention (Young 2008a). Public authorities sought effective, innovative alternatives to existing governance and management regimes to control market-driven fishing pressure.

The evaluation presented in this article focuses on nine case studies of adaptive, experimental interventions through action research in sea cucumber fisheries management, including one in New Caledonia and eight in Vanuatu (Figure 2).

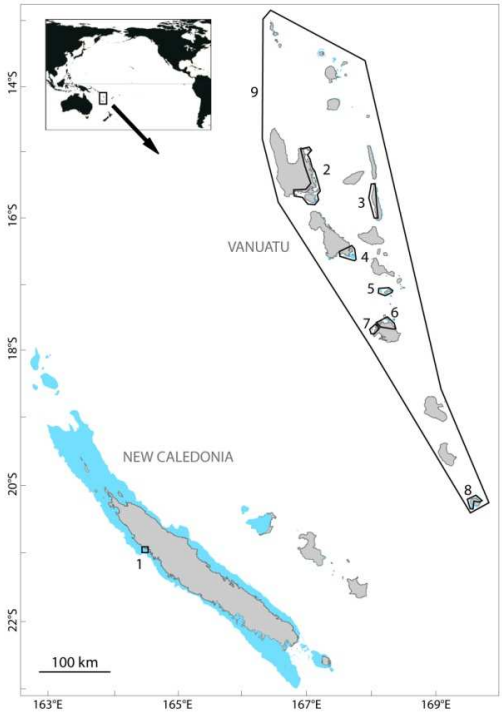

Figure 2. Location of case studies in Vanuatu and New Caledonia, South Pacific. Coral reef areas are represented in blue.

The spatial, social and political scales of the interventions varied across case studies (Supplementary material). Eight cases (one in New Caledonia and seven in Vanuatu) involved interventions at the local scale of community social units. One case located in Vanuatu concerned an intervention at the national level. This latter case included the seven local cases in Vanuatu as well as other sea cucumber fisheries of a large number of islands in the archipelago.

Characteristics of household livelihoods, reef fisheries management including community and government rules, and fisheries also varied across case studies. Reef fishing practices in the fisheries considered are organized and operated with limited technological capacities. In each case, sea cucumber fisheries were closed when our experimentation started due to resource depletion. As a result, fishers considered them as potential, future income-generating fisheries, when resources would have naturally regenerated through the establishment of effective management rules. Sea cucumber fisheries can indeed have significant impact on household livelihoods in those communities where alternative sources of income are limited (Supplementary material).

The case studies were selected to facilitate comparison. The socio-cultural and political Melanesian context described above applies to all the cases studies, which faced similar sea-cucumber fishery overexploitation problems. In addition, the interventions were homogeneously designed across these case studies and consisted in developing and implementing a cooperative, adaptive co-management regime for sea cucumber fisheries between local communities and the fisheries administration (i.e., government Fisheries Department in Vanuatu and provincial Fisheries Division in New Caledonia) as described by Léopold and al. (2013b). The interventions were built in two stages. A first experimentation

was developed in a small community in New Caledonia in 2008 (case 1, Supplementary material). Following this, a similar intervention was developed from 2010 in seven local cases (cases 2 to 8, Supplementary material) and at the national level (case 9, Supplementary material) in Vanuatu. A partnership was established in 2011 between researchers and the fisheries departments of Vanuatu and the Northern Province of New Caledonia within a regional political cooperation framework, which developed interactions between case studies and learning through reciprocal transfers of skills and knowledge (Keen and Mahanty 2006).

In all experimental interventions, the research approach followed the methodological principles of action research (McTaggart 1997) and transdisciplinary research for sustainability science (Lang et al., 2012), as adapted to fishery governance issues relating to marine tenure (e.g., Ernst et al., 2013; Abernethy et al., 2014). Action research aimed at developing institutional innovations in response to practical, complex fishery problems by initiating and/or fostering individual and collective social learning through action. Specifically, social learning was enhanced through short loops of cooperative actions repeated for several years, following a reflexive spiral of adaptive experimentation in each case (Figure 3).

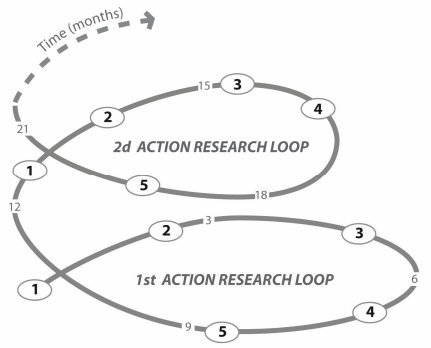

Figure 3. Action research reflexive spiral of the adaptive experimental process (derived from Liu 1997; Dickens and Watkins 1999)**.** A typical loop was composed of five collaborative steps: initialization (step 1: e.g., negotiation of ethical issues, the research design, the collective strategy, and the participating actors), diagnosis and prioritization of the problem(s) to be solved (step 2), action planning (step 3), action implementation (step 4), and impact assessment (step 5). The loop and between-step duration is indicative and flexible. Different sources of knowledge and capacities were mobilized, developed and shared between the actors during each step. A formal or informal organization may be set up to foster cooperation during the successive steps and loops.

Co-management arrangements including power-sharing interactions resulted from a cooperative problem-solving process within each case (Carlsson and Berkes 2005). The practice of co-management that was implemented included participatory biological monitoring of the sea cucumber resources and statistical biomass estimation by the fishery administration. The latter then recommended a spatially-explicit, collective TAC by species. This TAC-setting method aimed at regenerating resources following the precautionary approach while limiting transaction costs. The final decision to harvest all or part of the TACs and allocate fishing opportunities (e.g., open fishing period, use of non-transferable individual quotas, distribution

of catches, individual fishing rights) belonged to the communities within their marine tenure. The interventions were scaled according to the economic value of the fisheries and to the social organization within these. Consequently research engagement varied across case studies (Supplementary material).

Changes in the fishing systems studied were observed using quantitative and qualitative information collected using a participatory approach, following the institutional diagnosis approach defined by Young (2002, 2008b). Data was collected on the evolution of resource-use problems (including management and resource regeneration objectives, catch limits, enforcement of and compliance with rules), the political support at the provincial and national levels, and the evolution of collaborative and conflicting relationships among the actors involved. Perception data was collected through interviews and informal, opportunistic discussions with key informants, and numerous joint information and/or decision-making meetings that systematically connected community members and fishery department staff. Participatory monitoring was also conducted, including recording of catches (volume and sale prices per species) and spatial resource assessments of total biomass and size structure (Léopold et al., 2013b). Biological assessments were performed once or twice a year throughout the research period in New Caledonia (case 1) and only once in each local case in Vanuatu (cases 2 to 8) because of survey costs and low biomass across these cases (Léopold et al., 2015). In those cases, resource levels for unobserved years were inferred based on an assumed low annual level of biological population growth (10% per year), given the low growth rate of most tropical sea cucumber species (Uthicke et al., 2004). This data was recorded in confidential internal notes and diagnosis reports to fisheries administrations, as synthesized by Léopold et al. (2013a, 2013b, 2015) and Léopold (2016). The detailed observations of the institutional process and its outcomes allowed assessing institutional change in the case studies throughout the research period (Supplementary material). These diagnoses were used as secondary data to inform the assessment of intervention impacts presented in this article.

3.2. A multidimensional evaluation framework

We used a multivariate assessment approach to assess the impacts of interventions on institutional change and on sustainability of the fishing systems (Mitchell 2008). Evaluation of the performance of the institutional setup involved identifying the factors that strongly affect the success or failure of co-management arrangements, based on a literature review. Contextual factors that remained unchanged during our research or were common to all the case studies (e.g., territorial access rights, ability of users to define catch allocation rules, nature of the management rules, resource boundaries) were not included in the analysis.

From the primary data acquired through the institutional diagnosis, eleven evaluation criteria were retained (see Table 1 and supplementary material for a description of these criteria). Those criteria included four outcome criteria (actors' behavior, level and evolution of high value resource biomass density, and percentage of the maximum catches observed), five instrumental criteria (enforcement, government support, individual learning, capacity for action, and organization), and two interactional criteria (actors' strategies and collective learning).

Institutional performance was characterized by the combination of values taken by these eleven criteria for each year of the experimental intervention. The number of scoring categories of each

criterion was defined according to the accuracy of the available information (Young 2002), and the categories themselves, for each criterion, were logically ordered according to a performance gradient of the criterion, in order to facilitate interpretation of those categories. This was repeated separately for each criterion. The resulting scoring categories for each criterion are explicitly described in Supplementary material.

The annual scores for each of the criteria were evaluated in 2017 immediately after the end of the research in the case studies. The validity of these scores is strongly based on the detailed knowledge accumulated by the researchers from the institutional diagnosis conducted during the fishery-by-fishery field research. The process of assigning these annual scores may be sensitive to researcher subjectivity, especially for instrumental and interactional criteria (Mitchell 2008; Armitage et al., 2017).

In order to identify the variables that influenced the dynamics of institutional performance, and to compare temporal trajectories across the nine case studies, a multiple correspondence analysis (MCA) was carried out using the multivariate analysis grid. Each observation in the analysis corresponds to a case-year pair (i.e., 56 observations in total), and was described by the eleven performance criteria (Supplementary material).

First, variability of and possible interactions between the criteria were analyzed. The respective contributions of the criteria categories to the two first dimensions of variation in the scores were calculated to interpret these factorial dimensions. The 95% confidence ellipses of each criteria category were projected into the main factorial plan of the MCA to assess whether the categories of each criterion were significantly different from each other. A small (respectively large) distance between criteria in this plan indicated strong (respectively weak) interactions between these criteria.

Second, the inter-annual evolution of institutional performance was analyzed within and between cases. The temporal trajectory of the institutional performance profile in the case studies was interpreted according to the above characterization of the first two dimensions. A small (respectively large) distance between two cases in this plan indicated a strong (respectively weak) similarity between these cases. In other words, the distance between successive representations of the institutional profile of a given case was interpreted as inter-annual change in this profile. A typology of trajectories was then visually interpreted to discuss the main patterns of institutional change across case studies. Multivariate analysis was performed in R using the FactoMineR package (Lê et al. 2008).

Table 1. Criteria of the multidimensional assessment framework of institutional performance. Eleven criteria are included: actors' behavior, catches, biomass level, trend in biomass, enforcement, government support, individual learning, capacity for action, organization, actors' strategies, and collective learning. The expected change in score during the adaptive experimentation is indicated. See Supplementary material for more details of criteria score levels.

Governance criteria	Number of score levels	Rationale and expected change in criteria score
Outcome criteria		
Actors' behavior (Behavior)	3	Change in actors' behavior in both the fishery and governance sub-systems was a condition required for observing any impact of the intervention on the fishery. This change would reflect how the actors deal with social cooperation dilemmas. The intervention was expected to induce change in fishery and governance actors' behavior for effectively controling fishers' activities and the resulting pressure on the resources.
Resource biomass (Biomass)	3	The biomass of high value species (t/km²) was the biological outcome of all other governance criteria (except Trend in biomass). The intervention was expected to prevent sea cucumber resource depletion and maintain resource biomass at sustainable level.
Trend in biomass (Biological trend)	3	The observed trend in biomass of high value species was a biological incentive for institutional development. The intervention was expected to increase resource biomass in the case studies through co-management.
Relative catches (Catch)	3	Catches of high value species generate economic incentives to fishers for contributing to cover transaction costs of institutional development. The intervention was expected to develop a small fishery allowing for regular, limited catches. The maximal catches observed in each fishery during the intervention was used as an obviously unsustainable level. A reference threshold (0.35 times that maximal catch level) was empirically used based on biological and catch monitoring records in case 1.
Instrumental criteria		
Enforcement	4	The use of individual social and/or economic sanctions for breaking the rules is a necessary condition to prevent free-riding. The intervention was expected to establish progressive, effective, and deterrent sanctions, in coordination with the relevant local fisher organizations, local authorities, and government departments through co-management.
Government support (Legal)	3	Because of the strong, global market pressure on the fishery, public support to the institutional process was a necessary condition to govern fishing activities. The intervention was expected to allow for designing insitutions that would be perceived as legitimate and officially supported through co-management.
Individual learning	3	The common understanding of systemic processes by all relevant actors was a necessary condition for defining and implementing context-specific, effective, and cooperative insitutions through adaptive co-management. The intervention was expected to improve individual learning through i) better knowledge of the fishery, sustainability problems, and potential impacts of institutional change, and ii) higher knowledge transfer effectiveness and transparency.
Capacity for action (Action)	4	Technical, financial, and political administrative capacities for action should fit the fishery context (e.g., expected economic returns, extent and homogeneity, contribution to community livelihoods), problem, and institutional change. The intervention was expected to develop, specialize, coordinate, and sustain cross-sectorial and multi-level actors' capacities to reach fishery sustainability targets.
Organization	3	A lasting, multi-level organization would allow for developing strong social interactions between fishery actors. The intervention was expected to establish an informal, multi-level organization to facilitate cooperative actions and decisions at the system scale.
Interactional criteria		
Actors' strategies (Strategy)	3	Heterogeneous actors' preferences within the fishery and/or governance sub-systems may lead to diverging individual or collective strategies, which would preclude cooperation. The intervention was expected to identify key-actors' interests and objectives and to define acceptable collective management strategy and outcomes.
Collective learning	3	By promoting social interactions, collective learning promotes shared vision and collective objectives and strenghthens trust between actors and cooperation. The intervention was expected to develop regular, sustainable horizontal and vertical relationships within fishing systems, and to link actors across similar systems. Bridging organizations may facilitate those interactions.

4. Results

4.1. Change in and interactions between criteria of institutional performance

The main factorial design accounted for 40.6% of the variation in scores, which suggests that the first two dimensions of the multiple correspondence analysis (MCA) effectively represented the variability of the governance performance in the case studies. All outcome (except *Biomass*), instrumental and interactional criteria contributed significantly to those dimensions, which shows the multidimensional impacts of the experimentations on the fishing systems studied. The scores of these ten criteria were significantly different from each other, with the exception of the *Enforcement*-3&4 and *Legal*-2&3 scores as shown by their overlapping ellipses (Figure 4).

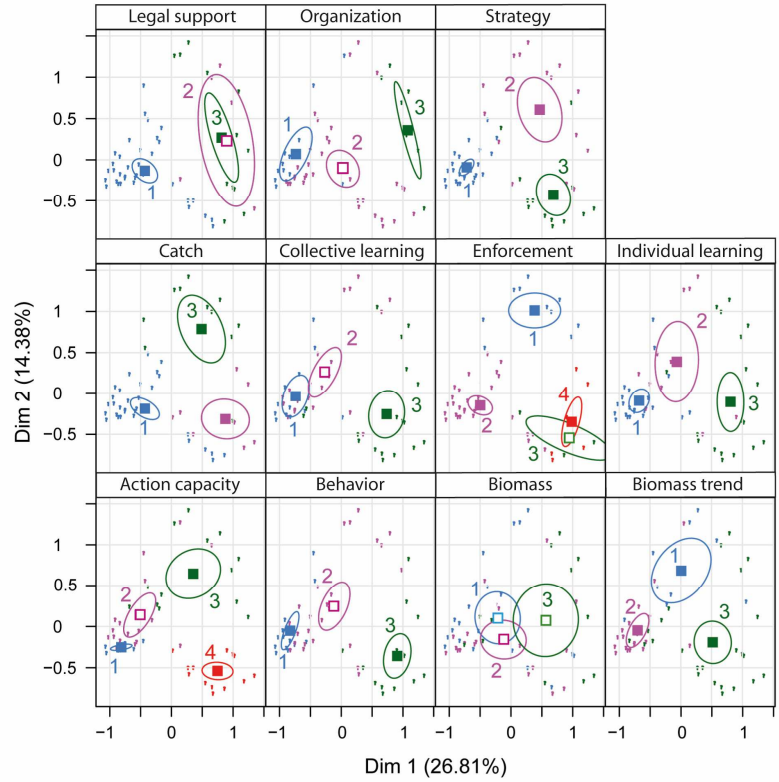

Figure 4. 95% confidence ellipses of the scores of each governance criteria within the main factorial plan of the multifactorial component analysis. Significantly different scores for each criterion are represented by ellipses that do not overlap. Ellipse colors refer to criteria score levels (see Table 1 and supplementary material). Criteria that significantly contribute to dimensions 1 or 2 are represented by filled (dark) squares while criteria that did not significantly contribute to dimensions 1 or 2 are represented by open (white) squares. Dots represent overall annual performance of cases (n=56).

The first two dimensions in the MCA characterized three institutional contexts with different score and criteria combinations. The first combination (group A criteria and corresponding scores, Figure 5) is characterized to limited institutional performance that was typically diagnosed in several case studies in Vanuatu when the co-management process started. This group corresponds to the implementation of a national moratorium on the sea cucumber fisheries in the country (*Catch*-1), which was established following an obvious collapse of catches and poor knowledge of fishery dynamics (*Individual learning*-1). The moratorium was

an easy-to-implement institution (*Action*-1) that was effectively enforced by the government fisheries department (*Enforcement*-2) through conventional top-down governance (*Organization*-1, *Behaviour*-1, *Strategy*-1, *Collective learning*-1). This closure allowed the slow regeneration of the resources (*Biomass trend*-2), the biomass of which was estimated to be very low to low (*Biomass*-1 or *Biomass*-2) at the beginning of the intervention.

The second combination (group B criteria and corresponding scores, Figure 5) is characterized by intermediate scores for the six criteria. It captures rational overexploitation of resources that had been previously stockpiled (*Catch*-2, *Biomass trend*-1), as a result of enforcement failure (*Enforcement*-1). This situation occurred despite individual understanding of the predictable effects of fishing on resource depletion (*Individual learning*-2). Other criteria scores indicated poor understanding of institutions, insufficient coordination of action capacities (*Action*-3), and poor engagement of key actors in the collective strategy (*Strategy*-2). Interestingly, this score combination was observed regardless of the score of four outcome (*Biomass*), instrumental (*Legal* and *Organization*) and interactional (*Collective learning*) criteria in the case studies.

The third combination (group C criteria and corresponding scores, Figure 5) is characterized by high scores of all institutional performance criteria. It represents the optimal situation that was observed throughout the co-management intervention process in the case studies, although the associated level of resource biomass (*Biomass*) was very variable across cases, as a function of initial ecological conditions (scores 1 to 3).

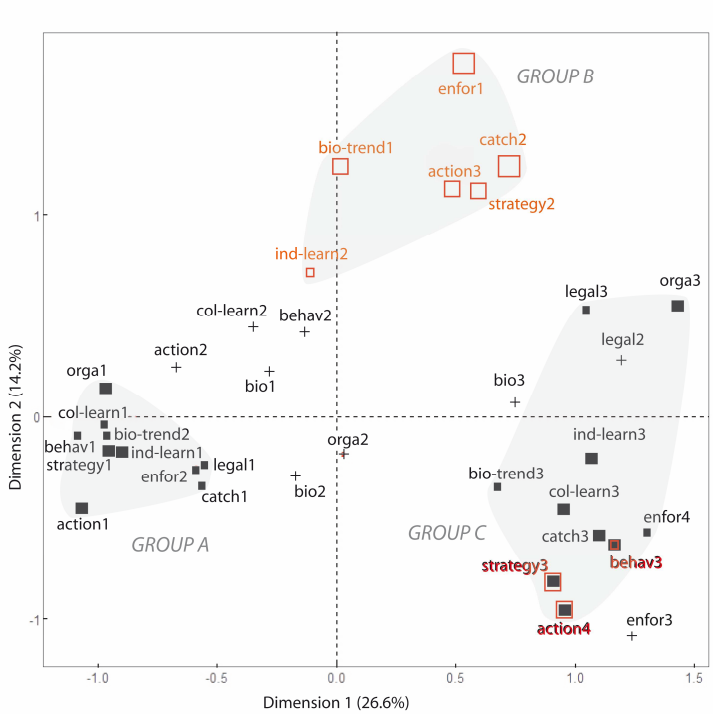

Figure 5. Three institutional contexts emerging from the analysis of institutional performance criteria. Based on the first and second dimensions of the multifactorial component analysis, significant categories are represented by black (for dimension 1) and red (for dimension 2) squares using a three-level scale (<5%, 5-10%, and >10% relative contribution). Grey areas represent the three institutional contexts based on interaction of significant criteria scores (groups A, B, and C). Criteria and scores that did not significantly contribute to dimension 1 or 2 are represented by crosses. Criteria name abbreviations: Behavior (behav), Biomass (bio), Biomass trend (bio-trend), Enforcement (enfor),

Individual learning (ind-learn), Collective learning (col-learn), Organization (orga), and Legal support (legal).

4.2. Dynamics of institutional change

Institutional change in the case studies was interpreted based on multi-criteria evaluations as described above, examining within- and between-case inter-annual change. The trajectories of the case studies showed that the overall institutional performance changed strongly during the research period. Diagnosed changes included different criteria, followed different directions, and happened at variable speed across cases and periods. Three trajectory types were observed (Figure 6).

Type 1. The unidirectional Type 1 trajectories involved two local case studies in two Vanuatu islands (Figure 6a), and corresponded to a gradual increase of the scores across all governance criteria during the experimentation. This trajectory type can therefore be interpreted as improvement of the institutional performance to situations of effective, although non-optimal, cooperation and control of fishing effort during the intervention. Specifically there was a transition from a context characterized by Group A scores (with the notable exception of *Behavior*-2, *Organization*-2, and *Collective learning*-2&3) to Group C scores during a period spanning five years. Five criteria reached optimal scores in the second year (*Biomass trend*-3, *Individual learning*-3, *Action*-4, *Strategy*-3, and *Collective learning*-3). The scores of three criteria however decreased (*Catch*-1, *Legal*-1) or remained moderate (*Organization*-2) at the end of the intervention following the national closure of the fishery in Vanuatu in 2016.

Type 2. The Type 2 trajectory was based on a single local case study in New Caledonia (Figure 6b), and represented more complex dynamics, characterized by three successive three-year cycles. During the first cycle, institutional performance followed the sub-optimal Type 1 trajectory. Initial criteria scores (*Catch*-3, *Enforcement*-3, *Legal*-3, *Action*-2, and *Strategy*-3) indicated that the co-management process was already partially effective when research started, and by the end of the second year, the performance criteria reached optimal scores (except *Enforcement* and *Legal*), that were then maintained for two years. At the beginning of the second cycle, a shock caused a rapid evolution of six criteria towards group B scores (*Behavior*-2, *Catch*-2, *Enforcement*-1, *Action*-3, *Strategy*-2, and *Collective learning*-2), causing a sudden trajectory bifurcation. This indicates weak cooperation and ineffective governance in controlling fishing effort. Indeed, the five-fold increase of resource biomass over the first cycle markedly increased individual catch per fishing day (Supplementary material), which proportionally increased (i) the opportunity costs of closed fishing seasons and catch limits, and (ii) the expected immediate gains of breaking the rules, even over very short periods. This caused the defection of some key fishers with rapid, negative cascading consequences on the commitment of most fishers, provoking a governance shock. During the third cycle that characterized the post-shock period, the trajectory precisely followed the opposite path traveled during the second cycle, except for two criteria (*Strategy* and *Action*), indicating institutional performance had partly recovered.

Type 3. Type 3 trajectories were observed in Vanuatu in the national case and in five local cases (Figure 6c). They consisted of three cycles of different duration. During the first cycle spanning three to five years, institutional performance followed the Type 1 trajectory. During the first

two to four years, institutional change was limited to a few criteria, but this accelerated abruptly in 2014, coinciding with the trial of a TAC co-management strategy. The nature and number of criteria that increased to optimal or sub-optimal scores varied across cases, including at least four criteria (*Behavior*, *Biomass trend*, *Action*, and *Strategy*), which showed that co-management was effective that year. As occurred for Type 2 trajectories, the Type 1 trajectories then bifurcated during the second cycle, due to a shock caused by the interactive effects of various stresses that simultaneously occurred in the six cases. Indeed an intense tropical cyclone and drought hit the country in 2015 destroying subsistence and commercial crops in many communities across the archipelago, leading to a national socio-economic crisis. Sea cucumber resources suddenly represented a 'bonus' for generating income in communities. The government fisheries department consequently urgently set TACs and opened the fishery for four months only, which unintentionally pushed the local sea cucumber industry to maximize short-term gains. These market-driven effects were exacerbated by two other stresses. On the one hand, the national moratorium on sea cucumber fisheries in Vanuatu (2008-2013) had attracted the interest of international traders and local communities, who expected high economic returns despite the low resource biomass. On the other hand a change of governance took place at the head of the Vanuatu government fisheries department in early 2015, which disorganized its overall governance capacity.

This shock led to a *de facto* open access regime spanning four months (Supplementary material), that destabilized the cooperation that had been present during the first cycle of the trajectories. Scores of six to ten performance criteria (including *Behavior*, *Biomass trend*, *Enforcement*, and *Action*) decreased across cases. A larger number of criteria were affected in the local cases than in the national case. The third cycle of type 3 trajectories corresponded to the post-shock period that was characterized by a sudden bifurcation simultaneously in all cases, following the national closure of the Vanuatu fishery in 2016. The trajectories ended close to a state that had been previously observed during cycle 1, depending on the one to five criteria that changed. The new final state of the national case indicated that the scores of six governance criteria (*Behavior*-2, *Individual learning*-2, *Action*-3, *Organization*-2, *Strategy*-3, and *Collective learning*-2) improved compared to their initial situation, against only one (*Action*) to three (*Behavior*, *Individual learning*, and *Action*) governance criteria across the five local cases. A systematic decrease in biological outcomes (*Biomass*, *Biomass trend*) was also diagnosed, except in a local case where the initial biomass was already very low.

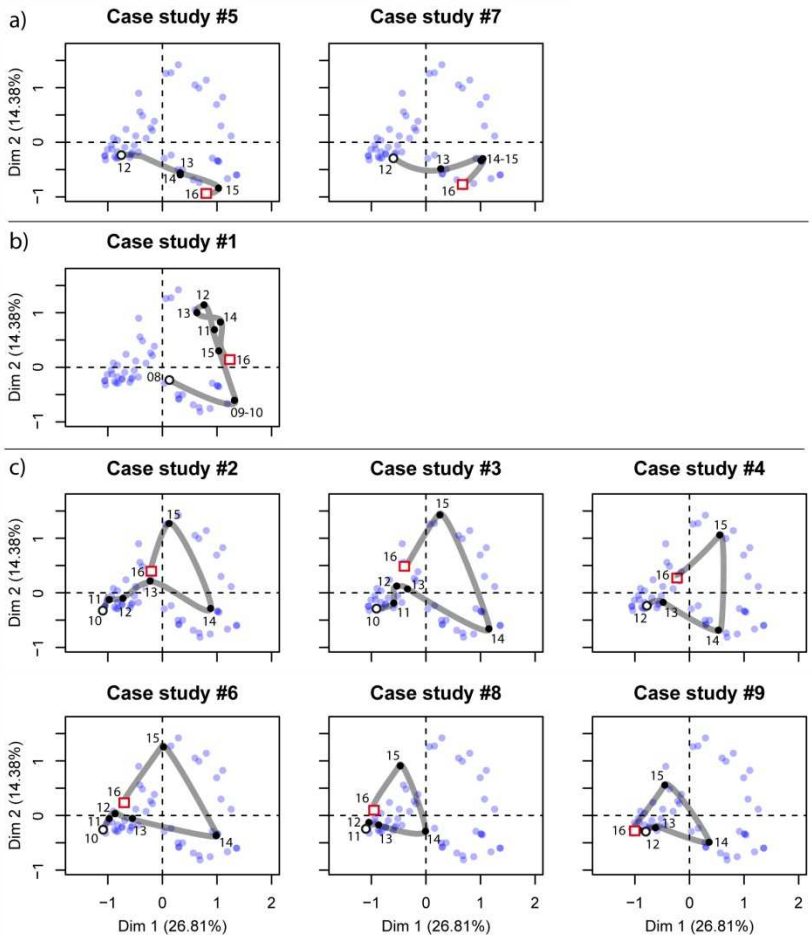

Figure 6. Dynamics of institutional change – A typology. Trajectories of case studies are indicated, represented by their annual institutional performance profile during the experimentation period. Cases belonging to type 1 (a), type 2 (b), and type 3 (c) trajectory are presented. Circles and squares show first and last research years in case studies, respectively.

5. Discussion

5.1. Overall impacts of the interventions

Our empirical evaluation framework and multivariate analysis enabled assessing the effects of the problem-solving adaptive experimentation interventions on institutional innovation and performance of small-scale sea cucumber fisheries in the South Pacific islands. The social arena of the case studies was taken into account as a contributing factor. The crafting of co-management was confronted with varying initial conditions, engagement of research, and local and global realities across cases. Common constraints to the application of adaptive experimentation also included ethical considerations as well as transaction costs (Cook et al., 2004; Armitage et al., 2008).

Following other authors (e.g., Batista et al., 2014), the design and implementation of cooperative co-management regimes and actions in our cases required a slow, case-specific process that typically spanned several years, during which the relations between social actors, including scientists, fishers, middlemen, and administrative and political actors, were reorganized. The structure and dynamics of cooperative institutions adapted opportunistically

to inevitable, although unpredictable, changes of the system characteristics and external stresses, taking advantage of short windows of opportunity as recommended by Olsson et al. (2006). Importantly, co-management dynamics varied according to the negotiating power of strategic stakeholder groups, who adapted their interactions with other actors making the most of the adaptive experimentation intervention for their own interests. The design and practice of co-management therefore necessarily took place within an institutional environment that had to incorporate a great diversity of contextual factors operating simultaneously, which was consistent to other studies (Olivier de Sardan 2005; Nunan et al., 2015).

One of the most striking results was the similarity of the positive changes diagnosed in the institutional profiles across all cases during the first three to five years of the interventions, i.e. during the pre-shock period (Fig 6a-c). Specifically ten out of eleven criteria representing the different components of institutional performance were positively impacted during that period: outcomes (actors' behavior, evolution of high value resource biomass density, and catches), instruments (enforcement, government support, individual learning, capacity for action, and organization), and social interactions (actors' strategies and collective learning). In each case, these criteria markedly improved and in some cases, reached optimal scores. Interestingly resource biomass status was associated with varying levels of institutional performance, indicating that any one-time biological resource assessment would not inform about the performance of institutions within that fishery. The pre-shock period prepared actors for the strong institutional changes planned and progressively initiated by the intervention as already observed in other social-ecological systems (e.g., Olsson et al., 2007).

The initial increase in institutional performance in all cases confirms that the interventions effectively impacted fishing system governance, through adaptive experimentation processes involving researchers strongly collaborating with government fishery departments, and working with local communities and other economic and political actors, through a problem-solving approach (also see Pomeroy and Viswanathan 2003; Carlsson and Berkes 2005; Beddington et al., 2007; Johnson et al., 2013). Adaptive experimentation, through the development of co-management systems and the multidimensional evaluation of their impacts, was an effective way for testing government-supported harvest strategies, and, more generally, fishery policy implementation. It showed that collective TACs, temporary openings and territorial fishing rights provided effective incentives for the implementation of multi-level governance arrangements in small-scale sea cucumber fisheries. This result was encouraging in the context of overexploitation of coastal fisheries in Pacific Island countries (Aswani 2005) and other regions worldwide. Interestingly, we found that formal government support to collective institutional design and enforcement improved the performance of the institutional building process, whereas the cases where these activities were provided only by the local communities showed mixed results (Figures 4, 5).

5.2. Developing adaptive and resilient capacities to multiple stresses

Multiple administrative, climatic and economic stresses of various natures and scales, and of internal and external origin, affected all case studies over the time frame of the study.

First, a market-driven shock was observed in seven out of nine cases. The increase in resource abundance, in all case studies, following the effective implementation of temporary fishery

openings and control of fishing effort, had undesirable effects on the institutional building process. By providing a solution to the overexploitation problem, the fishery crisis that justified the experimentation was de facto temporarily solved. Although this consequence seems trivial, in practice it undermined the initial collective motivation for constraining fishing activities, and resulted in diverging individual strategies. The "price of success" of the interventions was thus in some cases an increase in the propensity to rationally overexploit sea cucumber resources despite the fishers' understanding of the resource-uses dynamics and the effects of management rules. This provides an important lesson about how small-scale fishery co-management does or does not address overexploitation problems.

Second, the major climatic hazards that occurred in Vanuatu in 2015 brutally and indirectly increased the rate of discounting of future catches of sea cucumbers and urged the government to mitigate that large-scale hardship in the short term. The economic capital reflected in sea cucumber resources played the role of a socioeconomic safety net for households in most coastal rural areas. As a result, these effects caused a booming of fishing activities, which exceeded the governance capacities of the local communities and the government fisheries department.

Third, the involvement of new key actors in the government decision-making procedures strongly affected institutional innovation. Because those actors had not participated in earlier stages of the social learning process of the intervention, they may have reduced the governmental action capacity and collaborative relationships with other actors of the co-management regime, as observed during this research in Vanuatu. The multiple stresses described above generated interactive effects which acted as shocks on the institutional building process during the intervention (Young 2010). These sometimes exceeded the system's adaptive capacity, as documented in other sea cucumber fisheries (Kaplan-Hallam et al., 2017). Although adaptive and resilient capacities to stress were not included as performance criteria in our multidimensional diagnosis framework, the temporal trajectories of case study profiles were monitored over a period long enough to analyze the opportunistic response of fishery institutions to change in internal and external contingencies. The three types of trajectories identified clearly show that the consequences of these shocks on institutional performance have been different across cases.

Type 1 and 2 trajectories highlight the resilience capacity of the governance systems in the corresponding cases, defined as their ability to respond to stress by self-reorganizing and maintaining essentially the same configuration, functions and feedbacks (Walker et al., 2002). Specifically type 1 involved two cases that absorbed all shocks observed during the research period without any significant reorganization (Figure 6a), which highlighted their remarkably low vulnerability (Adger 2006). The Type 2 trajectory showed a marked, partly undesirable change in the governance profile for three years, subsequently to a market-driven shock, followed by a gradual, incomplete return to the sub-optimal performance profile diagnosed in 2014 following precisely a reverse pathway. Exposed to the same shocks as the Type 1 cases, the Type 3 cases reacted sharply. In these cases, governance was deeply and suddenly affected twice, in 2015 in direct response to shocks, and again in 2016. Governance reorganized in these case studies, highlighting the transformability of those systems (Folke 2006), though in two cases (Figure 5c, cases 8 and 9), the system's adaptive capacity seems to have been

insufficiently developed for coping with such shocks, with individual and collective learning remained remarkably weaker in both cases than in all other cases.

The widely different resilience capacity across cases developed during the pre-shock period, i.e. before and during the 3-year to 5-year co-management initiation and development process. Specifically, the period during which optimal scores of four criteria (i.e., individual and collective learning, capacity for action, and alignment of actors' strategies) was maintained was critical in developing a resilience capacity in our case studies, although the effects of the other criteria cannot be ruled out. This finding shows the need for consolidating short-term, successful impacts on institutional performance across those multiple dimensions simultaneously. Such a consolidation phase consisted in continuing the problem-solving, adaptive experimentation under the same highly performing governance outcomes and processes for a minimum period (two years in our case studies). This phase aims to develop sufficient learning-by-doing and transformative learning under high performance conditions to deal afterwards with common stresses in small-scale fisheries. Should this consolidation phase not be conducted (e.g., due to unexpected shocks, as in this study), our results suggest Type 3 trajectories may be predicted.

5.3. Implementing large-scale interventions in small-scale fisheries

Our methodological approach started with a problem-solving project in a small-scale case study in New Caledonia, and was then generalized and up-scaled in Vanuatu. Unexpectedly the national case has not evolved in parallel to the local cases in this country, despite the multi-scale governance interactions that were implicit in the co-management regimes and the government TAC-setting procedure. The difference in trajectories between local cases (Types 1 and 3) and the national case (Type 3) have indeed shown that the impacts of interventions and shocks were both scale-dependent and context-dependent. This empirical result confirms that interventions promoting large-scale co-management of small-scale fisheries might be defined at the level of policy units but that co-management arrangement should be fine-tuned at the level of the relevant social units concerned, and not by top-down prescriptions, as recommended by Ostrom (2007) and Armitage et al. (2008) among others.

In our study the relevant social unit for achieving high level co-management performance was found to be the local community, although the management strategy and governance principles were homogeneously defined at the national scale, and the effects of economic and environmental factors operated beyond the community level. Following the same logic as that of development projects, such a model for policy interventions would tightly link political and practical dimensions, taking into account the national, consensual justification of interventions and their operational implementation in the local social arena, respectively (Mosse 2005).

The necessarily higher transaction costs of such large-scale, context-specific, several-year-long co-management interventions must then be anticipated and shared across partners. Attempts to alleviate transaction costs by implementing more authoritative co-management actions in two case studies that involved a large number of communities resulted in less social capital development, lower improvement in institutional performance, and poorer adaptive capacities of the whole systems (Figure 5c, cases 8 and 9). Given the high transaction costs to initiate co-management, the investment in social capital through adaptive experimentation should be

balanced with the expected fishery benefits in the long term. During this process, bridging organizations may play a key role in local coordination and knowledge transfer between users, traditional authorities and external actors such as researchers and government agencies (Folke et al., 2005; Turner et al., 2014). For instance the non-governmental WanSmolBag Ni-Vanuatu organization has significantly strengthened the engagement of local leaders in adaptive experimentation in the case studies in Vanuatu, as part of its long-term collaboration with the government fisheries department (McConney et al., 2014). In several cases in this country (Supplementary material), participatory conservation and development projects also strengthened relationships between communities and the fisheries department and therefore indirectly supported multi-level co-management of the sea cucumber fisheries. More globally, our findings are supportive of other studies (e.g., Finkbeiner and Basurto 2015) suggesting that initiatives capable of promoting the organization and participation of horizontal networks of communities in government-supported fisheries co-management institutions seem essential for the cost-effective, successful implementation of small-scale fishery policy interventions.

6. Conclusion

This article explores institutional dynamics of the introduction of co-management in several small-scale fisheries in the South Pacific. An ex-post analysis is carried out of a set of adaptive experimentation projects spanning several years, in nine case studies, which allowed investigating the impacts and performance of these collaborative interventions in developing co-management institutions. Based on a multi-criteria institutional diagnosis framework, the study showed that institutional performance, across the multiple case studies, fits within three specific trajectory patterns, involving gradual and abrupt changes. It was seen that robustness of the fishery systems to multiple stresses required consolidation of the institutional changes achieved by the interventions. Methodologically, this empirical study demonstrates a series of effective, action-research based methods to assess the dynamics of fishery institutional arrangements, and thereby to contribute to more effective crafting and sustaining of co-management regimes in small-scale fisheries.

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