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Exploration de la performance de la gouvernance des petites pêcheries du Pacifique sud par une démarche de recherche-action

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Thèse de doctorat

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Marc Léopold

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En tant qu'ingénieur de recherche à l'Institut de Recherche pour le Développement (IRD) depuis 2004, l'auteur a construit et mis en œuvre plusieurs projets scientifiques de recherche-action sur la problématique de gouvernance des pêcheries récifales dans le Pacifique sud, en interaction avec les divers acteurs concernés par ces pêcheries. Fruit de onze années de recherche, cette thèse de doctorat analyse plus particulièrement certains des travaux effectués pendant ses périodes d'affectation au centre IRD de Nouvelle-Calédonie (2005-2009) puis au Département des pêches du gouvernement du Vanuatu (2010-2014). Mettant à profit cette durée relativement longue, elle propose une relecture synthétique et une analyse approfondie de cette sélection de travaux, qui ont déjà fait l'objet de rapports de projets, de publications et de communications dans des conférences internationales. Cette exploration a permis la rédaction d'un nouvel article de synthèse et de deux nouvelles communications en 2018.

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INTRODUCTION GENERALE

1.1 Les petites pêcheries au sud : enjeux contemporains de durabilité

Avec 80 millions de tonnes produites en 2012 au niveau mondial, la pêche maritime continue d'assurer les moyens d'existence de près de 10 % de la population en dépit d'une progression rapide des produits d'aquaculture, qui devraient dépasser le niveau des captures mondiales dans le courant de la prochaine décennie (FAO 2014). Le secteur emploie directement près de 40 millions de personnes, un chiffre en augmentation de 43 % depuis vingt ans et qui suit la croissance démographique mondiale. La très grande majorité des pêcheurs en zone maritime opère dans le secteur de la petite pêche (ou pêche artisanale) dans les pays du Sud.

Très diverses à l'échelle mondiale, à l'image des sociétés humaines et des niveaux de développement des pays, les petites pêcheries maritimes s'inscrivent généralement dans l'économie familiale. Elles peuvent être définies par leurs caractéristiques technologiques et socio-économiques qui limitent leur extension géographique et les ressources ciblées à une zone côtière généralement proche des lieux d'habitation des pêcheurs – hors phénomènes migratoires (Panayotou 1982). Par opposition aux pêches industrielles, les petites pêcheries sont généralement administrées à des échelles spatiales réduites (i.e., 1-100 km) avec des capacités de financement, de gestion et de recherche plus faibles, en particulier dans les pays du Sud, alors que la main d'œuvre utilisée est plus abondante, les espèces exploitées sont plus nombreuses et les engins plus diversifiés. En conséquence, les connaissances sur les petites pêcheries sont généralement lacunaires, ce qui augmente l'incertitude sur les dynamiques halieutiques, écologiques et socioéconomique.

La durabilité des petites pêcheries est récemment réapparue comme un enjeu spécifique de première importance dans l'agenda international pour la lutte contre la pauvreté et la promotion de la justice sociale, l'emploi et la sécurité alimentaire (FAO 2012, 2015). L'attention pour les petites pêcheries s'est aussi développée depuis les années 1990 en réponse à la croissance des enjeux environnementaux et des projets conversationnistes dans les zones côtières d'une part, et à l'expansion de l'intérêt pour les approches décentralisées et spatialisées de gestion des pêches (Garcia et al. 2014a) d'autre part. Les contraintes structurelles et conjecturelles, couplées aux particularités des contextes sociaux et politiques, ont conduit à proposer des orientations de gestion innovantes et mieux adaptées aux petites pêcheries au Sud (Berkes et al. 2001).

Ce travail de doctorat s'inscrit dans ce contexte d'importants enjeux de durabilité des petites pêcheries, mais aussi de dynamisme et d'innovation des recherches halieutiques mondiales, en particulier au Sud. La communauté scientifique (toutes disciplines confondues) manifeste en effet un net regain d'intérêt pour les petites pêcheries depuis une décennie (Figure 1). Deux conférences mondiales ont ainsi été consacrées aux petites pêcheries en 2008 (FAO 2009) et 2014 (Kerezi et Ivani 2014) alors que la précédente édition avait été organisée par l'ORSTOM (futur IRD) près de vingt ans plus tôt, en 1989 (Durand et al. 1991). Ce travail s'inscrit dans cet effort de recherche mondial.

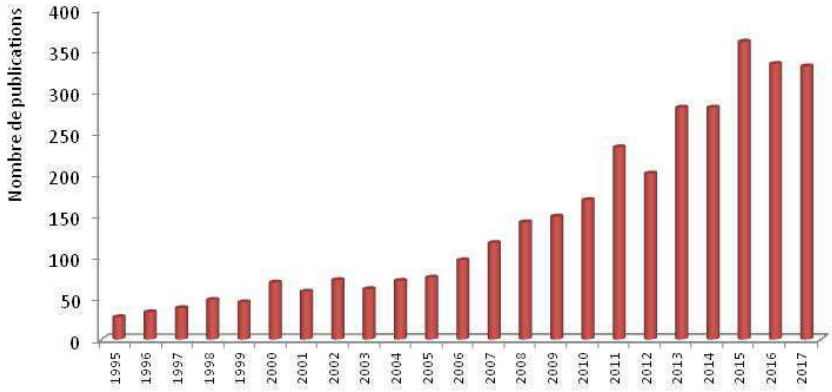

Figure 1. Nombre de publications anglophones annuelles portant sur les petites pêcheries* répertoriées dans le Web of Science depuis 1995. On observe un net essor des recherches sur les petites pêcheries à l'échelle mondiale depuis une dizaine d'années, bien que cette tendance haussière doive être relativisée par rapport à l'accroissement général de la littérature scientifique mondiale. * avec « small-scale fisher* » comme thématique.

1.2 De la gestion à la gouvernance des pêcheries

1.2.1 Gestion des pêcheries et représentation systémique

La recherche halieutique est longtemps venue en appui à une approche rationalisée de la gestion des pêcheries, appuyée par de solides développements théoriques (Graham 1935 ; Gulland 1968 ; Laurec et Leguen, 1981). Cette stratégie, qui reste dominante aujourd'hui, est axée sur un ajustement de l'effort de pêche à partir de considérations biologiques (i.e., le niveau et la structure des stocks), technologiques (i.e., la mécanisation et la modernisation des moyens de production) et/ou économiques (i.e., la rentabilité des pêcheries et les profits dégagés par les entreprises du secteur). Limitée à une gestion des activités de pêche orientée

par des objectifs de préservation des stocks halieutiques et de maintien de flux monétaires, la stratégie rationalisée repose sur une simplification des relations entre les ressources et les usages et des régulations descendantes de l'exploitation. Depuis une vingtaine d'années cependant, les actions et réactions des pêcheurs en réponse au contexte socioéconomique et aux régulations proposées ou imposées sont devenues des sujets de recherche prioritaires pour mieux rendre compte de la complexité et des dynamiques sociales, en particulier dans le secteur des petites pêcheries (Charles 1995). Les problèmes dynamiques et multisectoriels de ces dernières sont en effet difficiles à aborder sans une approche globale des problématiques de gestion et de gouvernance, en particulier quant à l'acceptabilité sociale des dispositifs réglementaires (Catanzano et Rey 1997 ; Chaboud et al. 2000).

L'approche systémique des pêches s'est imposée face à l'échec fréquent de la gestion rationalisée, et, dans les pays du Sud, des programmes de développement des petites pêches. D'un point de vue fonctionnel, un système halieutique peut être défini comme une organisation d'éléments en interaction dynamique, mettant en jeu des niveaux de décision hiérarchisés ou partagés en vue de valoriser des ressources (Brêthes et Fontana 1992 ; Rey et al. 1997 ; Berkes et al. 2003). Cette organisation a été conceptualisée sous la forme d'un système socio-écologique ouvert, composé d'un sous-système de production (i.e., la pêcherie *sensu stricto*) combinant deux compartiments écologique et humain, et d'un sous-système de gouvernance (ou de décision), lesquels répondent à des facteurs extérieurs (Figure 2). Ces sous-systèmes ont des niveaux variables de diversité, complexité, dynamique et vulnérabilité en fonction des contextes (Kooiman et Bavinck 2005).

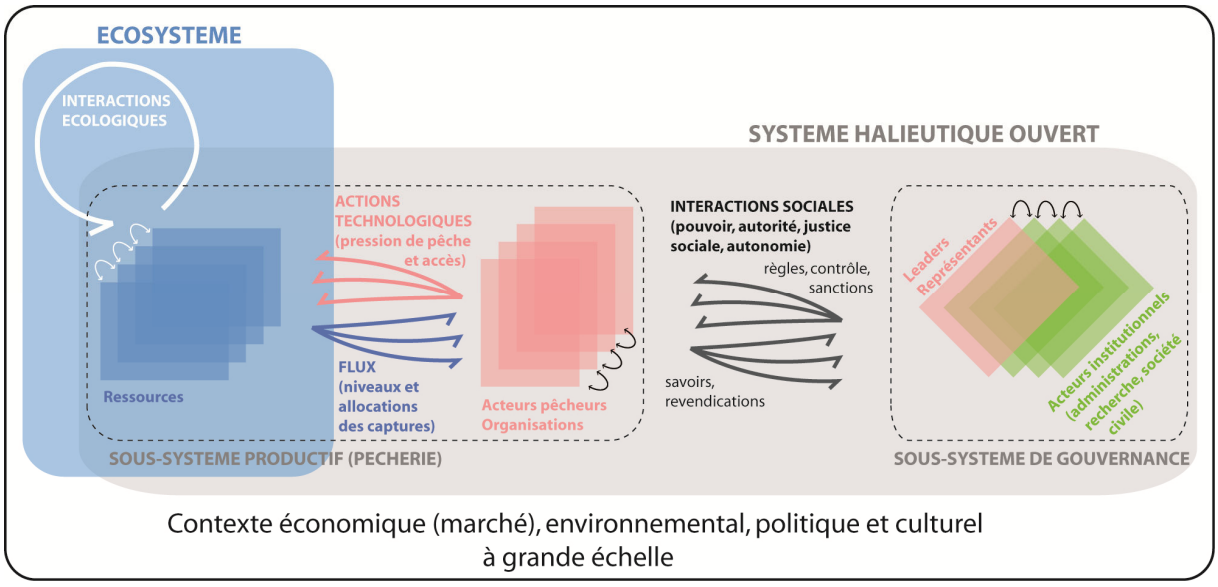

Figure 2. Représentation conceptuelle d'un système halieutique ouvert (modifié d'après Rey et al. 1997 ; Charles 2001 ; Kooiman et al. 2005). Les flèches représentent des actions technologiques (en rose), des flux de produits halieutiques (en bleu), et des interactions sociales verticales et horizontales (en noir). Les sous-systèmes de production et décisionnel sont représentés.

La représentation systémique traduit le fait que les problématiques sociales sont déterminantes sur la dynamique des relations entre les ressources et les pêches, et donc sur la durabilité de l'exploitation halieutique (Chauveau et Jul-Larsen 2000 ; Béné 2003). Plus spécifiquement, cette représentation est utilisée ici pour souligner deux aspects de la gouvernance. D'une part, celle-ci apparaît comme un facteur majeur de la transformation des usages des ressources, et donc de la gestion des pêcheries, laquelle est de nature technique et instrumentale. D'autre part, la gouvernance intervient alors selon les échelles sociales et spatiales des composantes des deux sous-systèmes, leurs temporalités et dynamiques différentes, et les interactions sociales verticales et horizontales (Dietz et al. 2003).

1.2.2 La gouvernance des pêcheries comme objet de recherche

La gouvernance des pêcheries regroupe l'ensemble des interactions entre acteurs visant à résoudre des problèmes sociaux ou à créer des opportunités sociales (Kooiman 2003). En d'autres termes, elle se rapporte aux règles formelles et informelles, à leur élaboration, et aux réseaux d'acteurs qui influencent la manière d'identifier, de définir et de mettre en œuvre des initiatives de gestion et de régulation des pêches (Armitage et al. 2017a). Elle doit permettre de valoriser les potentialités écologiques et socio-économiques des ressources en fonction des préférences sociales et de la manière dont celles-ci s'expriment. Ces dernières relèvent des intérêts, objectifs et stratégies des acteurs au sein d'arènes sociales, qui ne peuvent pas être appréhendées par une représentation systémique des pêcheries (Crozier et Friedberg 1977 ; Olivier de Sardan 2005).

Les caractéristiques de la gouvernance influencent fortement les incitations et motivations individuelles à adopter des mesures de gestion contraignantes, la probabilité et l'horizon temporel des impacts des décisions, les coûts de transactions associés au développement d'actions coopératives, et la distribution des bénéfices et des coûts induits par la mise en œuvre de ces dernières (Hanna 2014). Parce que les pêcheries répondent typiquement à des effets incertains, imprévisibles, d'origines différentes et d'intensité variable, ces caractéristiques doivent pouvoir s'adapter ou se transformer pour prendre, dans les délais impartis, des décisions de gestion qui soient écologiquement et socialement acceptables (Folke 2006; Young 2010). Le mode et les actions de gouvernance transcrivent ainsi les problèmes d'exploitation des ressources en des questions d'ordre social et politique, et déterminent *in fine* fortement la trajectoire des petites pêcheries. Ces interactions dynamiques ont justifié l'intérêt de considérer la gouvernance des pêcheries comme objet de recherche dans un nombre croissant de travaux depuis une quinzaine d'années, dont la présente thèse.

1.2.3 Institutions, gestion des ressources communes, et gouvernance des pêcheries

Notre recherche s'appuie sur les fondements empiriques et théoriques de la nouvelle économie institutionnelle concernant l'action collective et la gestion des ressources communes, développés selon une approche interdisciplinaire depuis une quarantaine d'années (Olson 1965 ; Ostrom et Ostrom 1977 ; Axelrod et Hamilton 1981 ; Axelrod 1984 ; National Research Council 1986 ; Feeny et al. 1990 ; Ostrom 1990). Sur le plan matériel, les ressources communes peuvent être analysées à partir des concepts économiques de production et de consommation conjointes, d'indivisibilité et d'exclusion (Oakerson 1986). A la différence des biens publics et privés, les ressources communes comme les ressources halieutiques sont ainsi caractérisées par les principes de rivalité d'usage et d'excluabilité (à un degré variable et ajustable) des usagers.

Les travaux sur la gestion des ressources communes reposent sur l'observation que les usagers peuvent, dans certaines conditions, élaborer eux-mêmes certaines solutions collectives à la « tragédie du libre accès » (Feeny et al. 1990 ; Ostrom 1990). Ces solutions coopératives prennent la forme d'institutions, définies comme un ensemble de règles, normes, croyances, rôles, lois et mécanismes pouvant être définis et mis en œuvre pour contraindre et faciliter l'organisation et les actions humaines (Ostrom 1986). Les institutions déterminent par exemple les arènes décisionnelles, les actions autorisées ou interdites, l'ajustement des conditions sociales et spatio-temporelles d'excluabilité, le régime des sanctions, l'information à recueillir, et/ou les bénéfices obtenus.

Les nombreuses actions collectives documentées de manière empirique et la possibilité d'une création endogène d'institutions s'opposent ainsi aux analyses selon lesquelles la surexploitation des ressources communes ne peut être résolue que par une intervention autoritaire externe aux systèmes considérés ou par l'allocation de droits d'accès individuels privés à ces ressources. Ces bases empiriques élargissent les hypothèses de l'économie conventionnelle, lesquelles stipulent que le fait économique résulte d'individus autonomes, opérant des choix individuels rationnels en fonction de contraintes extérieures définies, de l'information disponible et de leurs propres préférences, dans un contexte asocial et apolitique.

De très nombreuses recherches ont analysé le processus institutionnel et les conditions incitant les acteurs à s'organiser, à définir des institutions et à les respecter (Ostrom et al. 1999 ; Agrawal et Goyal 2001 ; Ostrom et al. 2002 ; Dietz et al. 2003 ; Berkes 2005 ; Ostrom 2009). Elles ont abondamment montré d'une part que les facteurs favorisant la création et la durabilité des institutions sont multiples et complexes, et d'autre part que la nature, l'impact, et l'évolution des institutions dépendent étroitement du processus de création et de mise en œuvre de ces dernières (e.g., imposées aux usagers des ressources, définies par eux seuls ou en relation avec d'autres acteurs selon une logique partenariale). Les institutions sont ainsi le résultat d'interactions sociales qu'elles influencent en retour, et sont donc au cœur du concept

de gouvernance défini plus haut (Jentoft 2005 ; Kooiman et Bavinck 2008). Dans notre recherche, nous analyserons ainsi la gouvernance des pêcheries comme un processus social de développement institutionnel.

1.3 La démarche de recherche-action en économie institutionnelle

1.3.1 Bases épistémologiques de la recherche-action

Suivant ses fondements épistémologiques (Liu 1997 ; McTaggart 1997 ; Dickens et Watkins 1999), la recherche-action vise à répondre de manière coopérative à des problèmes concrets explicités par les parties prenantes, en adoptant une approche holistique de ces problèmes. La démarche repose sur des cycles d'actions collectives, selon un processus adaptatif d'expérimentation en situation réelle (Figure 3). Différentes sources de savoirs sont mobilisées et l'information partagée entre les acteurs. Une organisation est généralement mise en place pour définir, mettre en œuvre et évaluer collectivement les actions aux différentes étapes du processus. En offrant une opportunité aux acteurs pour s'informer, discuter, réfléchir, exprimer les sources de conflits, expliquer les incertitudes, et clarifier et négocier les bénéfices et les risques attendus et observés, le processus collaboratif vise globalement à renforcer l'apprentissage individuel et collectif et à créer des incitations à s'engager dans des arrangements et des changements qui contraindront les usages en cours (Wilson 2002; Crézé 2006 ; Keen et Mahanty 2006).

La démarche de recherche-action formalise ainsi un processus adaptatif d'interactions et d'apprentissage social, tel que conceptualisé par Argyris et Schon (1996) sous la forme de boucles d'apprentissage imbriquées, opérant au niveau individuel ou collectif des systèmes sociaux. La boucle simple d'apprentissage concerne l'heuristique et la connaissance expérientielle acquise par l'action et par le suivi des règles. La boucle double est transformative : elle concerne la réflexion critique sur les règles et le possible changement de ces règles à travers le dialogue et la négociation, en fonction des normes et des valeurs des acteurs. Il est attendu que la démarche de recherche-action favorise ces deux niveaux d'apprentissage, en engageant simultanément un changement des pratiques et un changement dans la connaissance et la compréhension des processus socio-écologiques concrètement à l'œuvre (Ison 2016).

Dans le champ halieutique, la démarche de recherche-action s'apparente à une implication de la recherche dans un processus de gestion concertée et adaptative, afin d'appréhender les problèmes au sein du champ réel des relations sociales et d'articuler ces dernières avec les caractéristiques des ressources et de l'environnement (Perry et al. 1999; Catanzano et Rey

1997 ; Biais 2003 ; Tolentino et al. 2015). Les chercheurs interviennent alors délibérément comme des acteurs du changement institutionnel en interaction avec les autres acteurs du système considéré. Comme tout acteur, ils admettent leur rôle non neutre, qui dépend de leurs compétences, expériences, comportements, et valeurs individuelles (Neef et Neubert 2011).

Selon ces bases épistémologiques, il nous semble que la recherche-action peut contribuer de manière innovante à la compréhension du processus de développement institutionnel dans le secteur des petites pêcheries, bien qu'elle ait été rarement mobilisée en ce sens à notre connaissance.

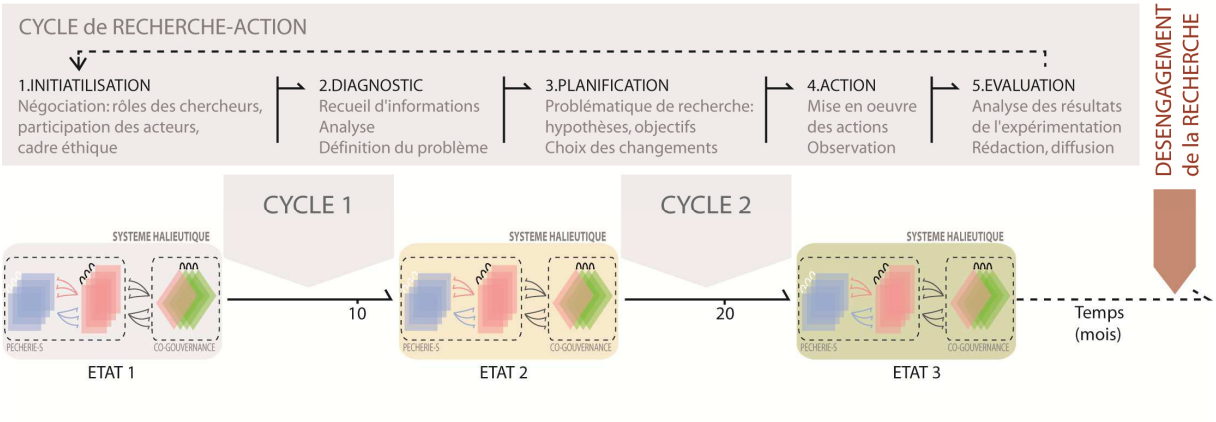

Figure 3. Démarche de recherche-action (d'après Liu 1997 ; Dickens et Watkins 1999). Chacune des cinq étapes est réalisée de manière collective en impliquant des chercheurs et des acteurs du système halieutique. La durée de chaque cycle est indicative et flexible en fonction des actions planifiées et réalisées. Le système halieutique change typiquement d'un état i à un état i+1 après chaque cycle.

1.3.2 La recherche-action dans le processus institutionnel

Le corpus épistémologique de la recherche-action s'inscrit dans la perspective de connaissance-action proposée pour analyser la nature et le rôle des institutions dans la gestion de l'environnement (Argyris et al. 1987 ; Blaikie et al. 1997 ; Young 2008a). Il a été mobilisé dans ce travail pour étudier la gouvernance des petites pêcheries suivant l'approche du diagnostic institutionnel.

L'approche par diagnostic institutionnel suit une logique interactionniste, orientée sur les relations entre acteurs, et cohérente avec le processus de développement institutionnel tel que décrit ci-dessus. Elle a été développée en raison de la complexité des interactions entre les nombreux facteurs affectant la durabilité et l'efficacité des institutions (Agrawal 2001). Elle se différencie de l'approche par diagnostic systémique d'Ostrom (2007), qui est certainement

l'approche par diagnostic la plus étudiée en matière de gouvernance des pêcheries (e.g., Basurto et al. 2013; Cinner et al. 2013). Cette dernière est basée sur la sélection et la documentation d'une part de certaines variables clés qui caractérisent l'état des différents compartiments des systèmes halieutiques (i.e., ressources, usagers, et gouvernance), et d'autre part des forçages externes, à différentes échelles temporelles et spatiales.

Le diagnostic institutionnel développé par Young (2002, 2008b) est quant à lui basé sur une analyse multi-échelle de l'arène sociale à travers quatre questionnements : quels sont les problèmes concrets à résoudre concernant les relations entre les usagers et entre les usagers et les ressources ? Quel est le contexte sociopolitique de ces interactions ? Quels sont les relations entre les acteurs impliqués ou à impliquer ? Quelles sont les pratiques courantes en matière de changement institutionnel ? Le diagnostic prend spécifiquement en compte les différents niveaux d'autorité légitime et de gouvernance. Il s'agit d'une approche d'analyse et d'interprétation visant à mieux prendre en compte les spécificités des situations locales dans l'élaboration des institutions, en rapprochant le milieu académique des enjeux réels et en produisant une connaissance propre au contexte.

Cette approche construit ainsi un processus d'apprentissage individuel et collectif et une dynamique institutionnelle qui impactent la nature même des institutions créées (Young 2002 ; Agrawal 2008 ; Underdal 2008 ; Poteete et al. 2009). En caractérisant l'arène sociale et en réfléchissant et agissant sur les facteurs de changement institutionnel, le diagnostic institutionnel offre une base méthodologique d'étude de la gouvernance des petites pêcheries qui est très cohérente avec la démarche de recherche-action exposée plus haut. Nous verrons ci-dessous comment le diagnostic institutionnel a été mis en œuvre dans nos recherches-actions sur la gouvernance des petites pêcheries.

1.3.3 Définition d'un modèle causal théorique de la recherche-action

La recherche-action relevant de l'expérimentation sociale en conditions réelles, un modèle causal des effets de ce type d'intervention sur le changement institutionnel est nécessaire pour appréhender les processus socio-écologiques sous-jacents en tenant compte des contextes de mise en œuvre. A partir du modèle conceptuel proposé par Stern et al. (2002) sur la gestion des ressources communes, le modèle théorique général de notre recherche sur la gouvernance des petites pêcheries a été défini. Suivant ce modèle, et reconnaissant le rôle déterminant de l'Etat et de ses administrations décentralisées dans le processus de gouvernance des petites pêcheries (Pomeroy 2003 ; Jentoft et al. 2005), notre démarche de recherche-action a accompagné une intervention par les autorités publiques sur le processus de gestion de ressources menacées de surexploitation (Figure 4). Une intervention regroupe un ensemble d'actions délibérées et influentes, dérivées des politiques publiques et du cadre législatif de la gestion des pêches. Elle se distingue donc de projets de recherche participatifs conduits à

l'échelle locale, à l'instigation d'organisations non gouvernementales ou d'institutions de recherche notamment (e.g., Wiber et al. 2009).

Selon le modèle, l'intervention, soutenue par la recherche-action, agit sur des facteurs intermédiaires (les médiateurs) qui influencent directement le processus de construction institutionnel (Figure 4). Les médiateurs incluent les instruments de gestion (e.g., capacités d'action et de mise en œuvre effective des institutions, production de données et de connaissances pour comprendre les relations de nature systémique entre les usages et les ressources, cadre légal) et les interactions sociales (e.g., apprentissage individuel et collectif, stratégies des acteurs) qui affectent directement les résultats de la gouvernance des pêcheries. Ces résultats sont les conséquences finales des effets des médiateurs dans le système halieutique : ils incluent des variables sociales (e.g., comportements des usagers et des autres acteurs, économiques (e.g., volume et valeur des captures), et biologiques (e.g., abondance et composition des ressources), lesquelles agissent sur les médiateurs via des rétroactions.

Le modèle implique en outre que ces trois facteurs et témoins du changement institutionnel (intervention, médiateurs et résultats) évoluent en fonction d'un ensemble de contingences (ou facteurs modérateurs). En pratique, ces contingences agissent en dehors d'un contrôle par les autorités publiques qui conduisent l'intervention et en caractérisent le contexte (Figure 4). Elles incluent des forçages externes (e.g., demande du marché mondial, effets environnementaux, contexte culturel) ainsi que facteurs internes liés aux caractéristiques des pêcheries (e.g., écologie des ressources, conditions socioculturelles, moyens d'existence des pêcheurs).

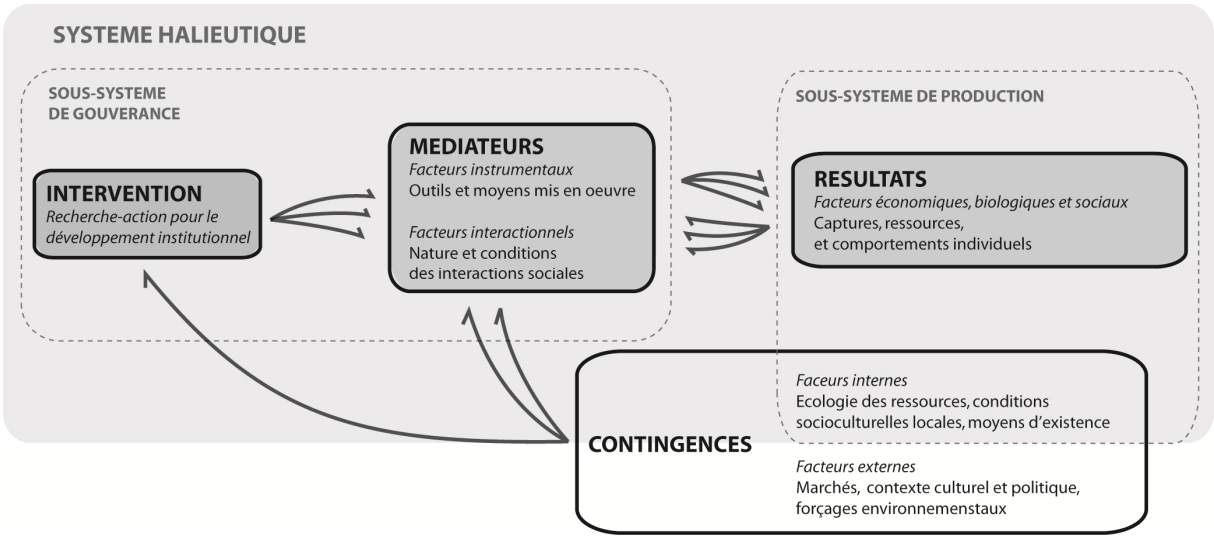

Figure 4. Modèle causal conceptuel du processus de développement institutionnel selon une démarche de recherche-action appuyant une intervention publique dans un cas donné (modifié d'après Stern et al. 2002). Les flèches indiquent les relations causales théoriques (cf. Figure 1 pour davantage de détails sur le système halieutique).

1.3.4 Objectifs et performance institutionnelle des interventions

A partir des très nombreux travaux sur les conditions de succès et d'échec des initiatives de gestion des ressources communes et de transformation de la gouvernance des pêcheries, une intervention structurée par notre recherche-action comportait les objectifs suivants :

1) Promouvoir des systèmes de gouvernance par cogestion entre les autorités publiques et traditionnelles et les autres acteurs des systèmes halieutiques, facilitant et organisant leur participation dans le processus de production de connaissances et de prise de décision ;

2) Promouvoir l'adaptation des institutions et de la gouvernance en fonction de la variabilité et de l'incertitude des systèmes halieutiques et des contingences ;

3) Promouvoir l'apprentissage social entre les catégories d'acteurs via une approche reconnaissant la pluralité des savoirs et la nature contextuelle des problèmes et des solutions expérimentées ;

4) Renforcer les capacités (d'action, de connaissances…) des acteurs pour conduire les différentes étapes des cycles de recherche-action.

Pour atteindre ces objectifs, l'intervention a typiquement développé une approche holistique et conduit progressivement des actions visant : à construire une vision partagée du système, à identifier les rôles et responsabilités respectives des acteurs, à mobiliser différentes sources de connaissances, à évaluer l'état du système et les problèmes d'exploitation halieutique, à établir des objectifs de gestion des pêcheries, à définir de nouveaux outils de gestion, et à expérimenter de nouvelles institutions en conditions réelles.

L'évaluation des impacts à court terme de l'intervention sur la performance des institutions est une question intrinsèque à la démarche de recherche-action et aux objectifs ci-dessus. Cette question renvoie d'une part aux critères (ou dimensions) de la performance à retenir, et d'autre part à la manière de les renseigner. Pour être efficace et convaincante, l'évaluation doit ainsi pouvoir être reliée avec suffisamment de certitude à l'action sur les institutions : elle doit donc intervenir pendant ou peu de temps après l'intervention et reposer sur des bases empiriques et causales (logiques) claires et transparentes, de manière à expliciter et réduire la subjectivité inhérente au processus d'évaluation (Mitchell 2008 ; Armitage et al. 2017a). Ce travail de thèse est ainsi basé uniquement sur des interventions de recherche-action que l'auteur a personnellement conduites et évaluées.

Suivant une évaluation multidimensionnelle de la performance institutionnelle (Mitchell 2008), les critères retenus ciblent en outre les facteurs processuels dont il est généralement admis qu'ils déterminent le succès des institutions dans la gestion des ressources communes (e.g., Young 2002 ; Kooiman 2003 ; Agrawal 2008 ; Ostrom et Basurto 2011 ; Armitage et al. 2017b). Selon le modèle causal défini plus haut, ces critères concernent à la fois les résultats des institutions et les médiateurs de l'intervention. L'impact sur les résultats des institutions a été évalué selon des critères factuels communément utilisés dans le suivi des pêcheries, et

concernant les captures, les ressources et le comportement des usagers. L'impact sur les médiateurs mobilisés pendant la recherche a été évalué selon des critères instrumentaux d'une part, rendant compte des outils et moyens mis en œuvre, et de critères interactionnels d'autre part, relatifs à la nature et aux conditions des relations entre les acteurs.

1.4 Problématique et objectifs de la recherche

1.4.1 Les pêcheries récifales dans le Pacifique sud, des laboratoires halieutiques

Notre recherche a été effectuée sur les pêcheries récifales des pays insulaires du Pacifique sud, confrontées à une pression et des signes de surexploitation croissants (Gillett 2010). Bien que ces petites pêcheries ne représentent qu'une part marginale de la production halieutique mondiale (<0,1 %), elles constituent de véritables laboratoires pour la recherche halieutique de par leurs conditions naturelles et sociopolitiques (Polunin et al. 1996).

Les pêcheries récifales du Pacifique sud sont peu professionnalisées, faiblement structurées et dotées de capacités technologiques souvent restreintes (Blanchet 1999). Elles sont en outre caractérisées par une grande diversité des écosystèmes exploités, source de complexité des systèmes halieutiques. Le nombre d'espèces de poissons et d'invertébrés exploités dans une pêcherie donnée est typiquement supérieur à une centaine, bien que les captures soient généralement dominées par 10 à 20% de ces espèces (Wright et Hill 1993 ; Dalzell et al. 1996). L'hétérogénéité spatiale des habitats marins (récifs et habitats associés : herbiers, algueraies, mangroves, lagons) se manifeste en outre à très petite échelle, de l'ordre de 0,1-1 km (Andréfouët et al. 2009), et se répercute sur la distribution des ressources et des pratiques de pêche (e.g., effort, rendements, engins utilisés).

Cette grande diversité a plusieurs conséquences pour la recherche halieutique. Elle se traduit tout d'abord par des connaissances lacunaires ou inexistantes sur la biologie (mortalité naturelle, croissance, taille à maturité sexuelle…) et l'exploitation de la grande majorité des espèces aux échelles spatiales appropriées à la gestion des pêcheries. Ces lacunes réduisent notamment l'applicabilité et la pertinence des modèles mathématiques mono- et multi-spécifiques sur la dynamique des populations récifales exploitées (Medley et al. 1993), y compris ceux utilisés pour prédire l'impact des changements globaux sur les pêcheries récifales (Bell et al. 2011). En revanche l'existence de différents contextes et gradients d'exploitation à différentes échelles (i.e., entre récifs, entre îles voisines, entre zones rurales et urbaines, et entre les pays de la région) facilite les études comparatives des effets de la pêche et de scénarios de gestion sur les ressources et les communautés récifales à partir de modèles spatialisés, comme les réserves marines (Jennings et Polunin 1995 ; Kronen et al. 2010). Les

conditions de visibilité et de faible profondeur permettent par ailleurs l'observation directe de certaines espèces et des relations espèces-habitat à différentes échelles, notamment via l'imagerie satellitaire (Andréfouët 2008), et leur utilisation pour l'évaluation des ressources et des usages (e.g., Gilbert et al. 2006).

Par ailleurs, les sociétés insulaire des îles du Pacifique sud ont été confrontées à des changements brutaux liés à la colonisation et à la commercialisation marchande à partir du 19ème siècle (à l'exception d'expéditions sporadiques antérieures), et à la création des Etats indépendants depuis moins de 50 ans. Dans les zones rurales, l'organisation sociale, traditionnellement basée sur le communalisme et la réciprocité (et donc des logiques de coopération), a généralement été transformée par des facteurs économiques, technologiques et politiques (Ward et Kingdon 1995). Elle a ainsi favorisé l'émergence d'initiatives communautaires de gestion de la pêche récifale à petite échelle (~1-10 km), gouvernées par des pratiques locales traditionnelles au sens wébérien (Johannes 1981, 1989). Ces systèmes imposent des restrictions locales sur des espèces, des périodes, des méthodes de capture et/ou des espaces spécifiques à chaque communauté et coexistent avec des régulations gouvernementales des pêches. Toutefois, à la différence de ces dernières, leurs motivations peuvent être autant biologiques que sociales et associées au maintien d'une tenure maritime coutumière (Foale et al. 2011).

Les pêcheries récifales de la plupart des pays du Pacifique sud sont ainsi caractérisées par la présence de deux ordres juridiques, l'un coutumier (formel ou informel) et l'autre civil. Ce pluralisme juridique, hérité du contexte socioculturel et de l'histoire postcoloniale, constitue une opportunité pour la mise en place d'institutions de cogestion (Bavinck et al. 2015). Enfin, les populations insulaires étant peu nombreuses (i.e., quelques centaines de milliers d'habitants), les structures administratives et politiques encadrant la pêche récifale sont de faible complexité à l'échelle nationale.

Les spécificités ci-dessus du contexte du Pacifique sud constituent des contingences internes et externes fortes des pêcheries récifales et de notre intervention de recherche-action. Elles ont été particulièrement informatives pour la recherche sur les institutions et la gestion contemporaine des ressources halieutiques, car elles sont *a priori* favorables à l'action collective, à la gestion spatialisée et à l'hybridation des niveaux communautaire et gouvernemental de gouvernance (Ruddle et al. 1992 ; David 1994 ; Adams 1998 ; Ruddle 1998 ; Agrawal et Gibson 1999 ; Berkes et al. 2001 ; Johannes 2002 ; Foale et Manele 2004 ; Aswani 2005 ; Cinner et al. 2005 ; Berkes 2006 ; McClanahan et al. 2006 ; White 2007), malgré certaines controverses ponctuelles (voir Wagner et Talatai 2007, et la réponse de Poteete et al. 2009). Les résultats acquis sur l'étude de la gouvernance des pêcheries récifales du Pacifique sud ont ainsi été et restent riches d'enseignements sur la gouvernance dans des systèmes halieutiques de dimensions plus importantes, dans d'autres régions et/ou d'autres écosystèmes.

1.4.2 Parcours et questions de la recherche

Notre travail est une contribution à l'élaboration d'un cadre de recherche pour étudier le développement institutionnel pour la gestion des ressources halieutiques communes. Appuyé sur une démarche de recherche-action, il propose un dialogue entre analyse et pratique des institutions, en confrontant les bases théoriques de la coopération à des observations empiriques.

Spécifiquement, ce travail s'appuie sur une analyse *ex post* de trois projets de recherche-action qui ont été effectués entre 2008 et 2016 dans deux pays insulaires du Pacifique sud, pendant des durées de cinq à neuf ans (cf. plus bas). La problématique a été construite progressivement au cours de ce long cheminement, qui a permis d'appréhender de manière empirique la temporalité et la variabilité du processus de développement institutionnel.

Notre recherche suit une démarche inductive. Comme dans de nombreux travaux sur les ressources communes, l'approche par cas d'étude a été utilisée comme méthode interprétative empirique pour analyser à la fois les processus de création institutionnelle, les effets de l'intervention sur ces processus, et leurs résultats sur les pêcheries (Poteete et al. 2009 ; Ray 2010 ; Ostrom et Basurto 2011). Suivant le modèle causal théorique ci-dessus, cette approche a consisté à étudier pendant plusieurs années le développement et la transformation d'institutions opérant à plusieurs niveaux de gouvernance, en tenant compte des dynamiques écologiques et sociales et des contingences multi-échelles. En provoquant délibérément le changement institutionnel, l'intervention crée en effet un contexte expérimental favorable à une telle étude, bien que l'intervention et donc la recherche-action aient été initialement motivées par les résultats opérationnels attendus.

Notre problématique est d'analyser comment l'intervention de recherche-action et les contingences des cas d'étude ont affecté, directement et/ou indirectement, la performance des institutions mises en place pour répondre à des problèmes de surexploitation des ressources récifales. Sans généraliser excessivement nos résultats basés sur un nombre restreint de cas d'études, cette problématique se décline en deux questions interdépendantes :

1) Sur le plan analytique, comment la démarche de recherche-action contribue-t-elle à la compréhension du processus de gouvernance et de ses impacts sur les petites pêcheries ?

2) Sur le plan pratique, selon quels mécanismes l'intervention de recherche-action renforce-t-elle l'action collective et améliore-t-elle la performance de la gouvernance des petites pêcheries?

Nous avons observé et interprété les trajectoires causales plausibles suivant les facteurs influençant la performance des institutions dans les cas d'étude, à partir des trajectoires hypothétiques du modèle théorique (Agrawal 2008). Ces facteurs (e.g., biologiques, économiques, culturels, politiques, stratégiques) structurant l'action collective et le

changement institutionnel sont étudiés dans différents contextes et à différentes échelles spatio-temporelles.

1.4.3 Les cas d'étude

Les trois cas d'étude ont été choisis dans le Pacifique sud, en Nouvelle-Calédonie et au Vanuatu (Figure 5), en fonction des connaissances disponibles relativement à notre problématique de recherche. Comme indiqué ci-dessus, les pays de Mélanésie partagent un contexte socioculturel et socio-institutionnel favorable à la gestion spatialisée et à la gouvernance multi-niveaux des pêcheries côtières. En Nouvelle-Calédonie, collectivité française *sui generis*, l'existence d'une tenure maritime coutumière affecte de manière effective les pratiques de pêche récifo-lagonaire et de gouvernance des ressources, bien qu'elle s'exerce sans fondement juridique. La pêche récifale autour des îles habitées se déroule sur le domaine public maritime et est administrée à l'échelle provinciale. Le Vanuatu, petit Etat insulaire indépendant depuis 1980, est un autre cas particulièrement intéressant car les communautés littorales y possèdent un droit constitutionnel de propriété sur les ressources récifales adjacentes à leurs propriétés terrestres. Ces communautés ont donc la double légitimité juridique et traditionnelle pour mettre en œuvre des régulations locales de la pêche sur leur territoire maritime. Elles sont en outre encouragées en ce sens par les autorités publiques, qui concentrent leurs efforts de régulation sur les ressources marines à forte valeur marchande, en particulier les invertébrés exportés (e.g., holothuries, trocas *Tectus niloticus*) en raison des retombées escomptées dans l'économie nationale, et les espèces dites emblématiques et protégées dans le cadre d'accords au niveau international (notamment par la Convention sur le commerce international des espèces de faune et de flore sauvages menacées d'extinction - CITES).

Les trois cas d'étude sont les suivants (Figure 5, Tableau 1) :

1) le cas d'une pêcherie locale de poissons récifaux au Vanuatu ;

2) le cas d'une pêcherie locale d'holothuries en Nouvelle-Calédonie ;

3) le cas de la pêcherie nationale d'holothuries au Vanuatu.

Ces cas correspondent à des ressources, des problèmes de gestion et des systèmes de gouvernance différents, bien qu'ils présentent les caractéristiques des petites pêcheries décrites plus haut. Leur complexité, leur échelle spatiale, la durée de la recherche-action et la nature des actions réalisées étaient également variables. L'analyse du processus institutionnel a été réalisée à l'intérieur de chaque cas d'étude et en comparant les cas d'étude.

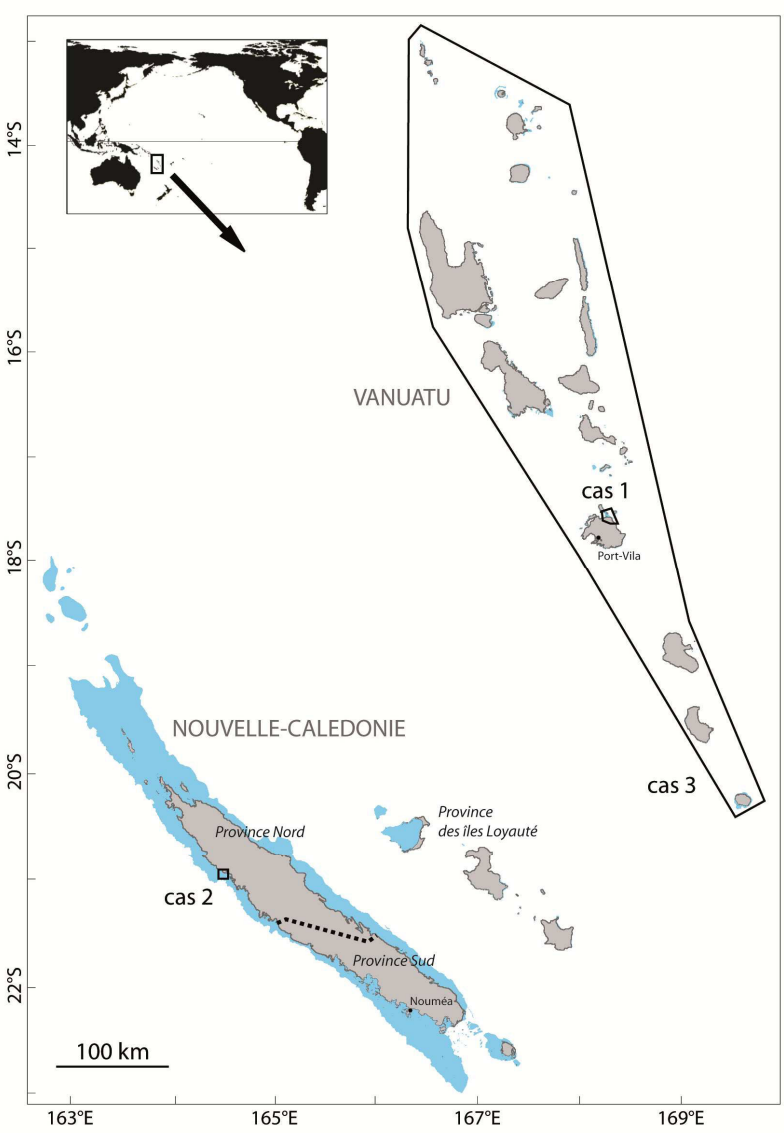

Figure 5. Localisation des trois cas d'étude en Nouvelle-Calédonie et au Vanuatu (Pacifique sud). Pêcherie locale de poissons récifaux au Vanuatu (cas 1), pêcherie locale d'holothuries en Nouvelle-Calédonie (cas 2), et pêcherie nationale d'holothuries au Vanuatu (cas 3).

Tableau 1. Caractéristiques des cas d'étude incluant le contexte géographique et socioéconomique, les pêcheries étudiées et l'intervention.
ONG: WanSmolBag, organisation non gouvernementale vanuataise. CPS : Secrétariat de la Communauté du Pacifique.

Cas d'étude	Caractéristiques												
	Contexte				Pêcheries							Intervention et recherche-action	
	Location	Echelle	Villages impliqués (nombre)	Principales occupations des ménages (par ordre d'importance)	Ressources ciblées (nombre d'espèces)	Zone de pêche (surface et profondeur)	Etat des ressources	Règles légales effectives	Règles communautaires effectives	Période de pêche pendant la recherche	Destination des captures	Période	Agences extérieures collaboratives
#1	Vanuatu (île d'Efaté)	Locale	7	Agriculture / pêche	Poissons récifaux (>100)	11 km² (0-25 m)	Forte exploitation	Pêche en plongée interdite	Droits territoriaux, réserves à ouvertures temporaires	2010-2014	Consommation locale, marché local (valeur commerciale faible)	2010-2014	IRD, ONG locale
#2	Nouvelle-Calédonie (province Nord)	Locale	2	Industrie / pêche / agriculture	Holothurie (1)	26 km² (0-5 m)	Surxeploitation de croissance	Pêche en plongée interdite, taille minimale de capture, license de pêche professionnelle	Droits territoriaux, fermeture temporaire	2008-2016	Marché mondial (haute valeur commerciale)	2008-2016	IRD
#3	Vanuatu	Nationale et locale (7 sites)	~470 63, 32, 11, 12, 19, 2, 7	Agriculture / pêche / tourisme	Holothuries (20)	780 km² (0-15 m)	Surexploitation de recrutement	Moratoire national (2008-2013), pêche en plongée interdite	Droits territoriaux, réserves temporaires, variables en fonction des villages	2014-2015	Marché mondial (valeur commerciale faible à haute)	2010-2016	IRD, ONG locale, organisation scientifique et technique internationale (CPS), agnece de développement du Japon (JICA)

La thèse comporte deux parties, suivies d'une conclusion générale :

- La partie 1 explore la pertinence d'une gouvernance multi-échelle des petites pêcheries, à partir d'une analyse de la gestion communautaire des pêcheries récifales au Vanuatu. Cette partie comporte deux chapitres complémentaires développés dans le cas d'étude n°1. Le chapitre 1.1 porte sur le développement d'interactions verticales entre les niveaux communautaire et gouvernemental de gouvernance des pêcheries récifales. Le chapitre 1.2 porte sur le développement d'interactions socio-spatiales horizontales dans un contexte de gestion communautaire en réponse à la dynamique spatio-temporelle des ressources récifales mobiles.

- La partie 2 analyse deux interventions pluriannuelles sur la gouvernance multi-échelle des petites pêcheries dans le cadre de politiques des pêches, à partir des cas de petites pêcheries d'holothuries surexploitées au Vanuatu et en Nouvelle-Calédonie. Le chapitre 2.1 analyse un processus d'intervention à l'échelle locale dans le cas d'étude n°2, pendant lequel une expérimentation adaptative de cogestion entre les communautés locales et les autorités publiques a produit des résultats biologiques et économiques positifs. Le chapitre 2.2 explore le caractère généralisable de ces résultats à différentes échelles temporelles et spatiales. Il examine la dynamique de la performance institutionnelle dans plusieurs pêcheries aux échelles locale et nationale dans les cas d'étude n°2 et n°3, à partir d'une grille d'évaluation multivariée.

PARTIE 1. Interactions verticales et horizontales structurant la gouvernance des petites pêcheries : la pertinence d'une approche multi-échelle

Introduction de la Partie 1

La gestion communautaire des ressources naturelles dans les pays du Sud a connu un net regain d'intérêt dans les années 1990 et 2000, en particulier dans le Pacifique, en raison du contexte socioculturel favorable évoqué dans l'introduction générale (e.g., Shackleton et al. 2010).

De nombreuses études réalisées à petite échelle ont ainsi montré que la gestion communautaire des pêcheries peut améliorer la mobilisation du capital social à différents niveaux, dont la production et la communication de connaissances, le respect des règles de pêche, la coopération entre les usagers, les capacités d'adaptation à des changements divers, et la gouvernance globale (McClanahan et al. 1997 ; Alcala 1998 ; Lobe et Berkes 2004 ; Berkes 2008). L'appui des administrations publiques et/ou d'organisations non gouvernementales (ONG) internationales à la gestion communautaires des pêcheries s'est également intensifié à travers des initiatives collaboratives de différentes natures, notamment dans le cadre de projets à durée limitée (Adams 1998). La gestion communautaire est ainsi apparue comme un mode de gouvernance locale des pêcheries à la fois multifonctionnel et performant, capable de répondre aux enjeux de conservation des écosystèmes et de durabilité des retombées socioéconomiques pour les villages littoraux.

Cependant, ce bilan enthousiaste des résultats escomptés de la gestion communautaire des pêcheries doit être nuancé (Blaikie 2006 ; Maliao et al. 2009). D'une part, les résultats positifs sont dépendants du contexte local (Cinner et Aswani 2007) et du temps, en raison de la sensibilité de la gestion communautaire aux changements de l'environnement, des relations sociopolitiques locales plus ou moins conflictuelles, et des pratiques de pêche (Ruddle 1998 ; Agrawal et Gibson 1999 ; Aswani 2005). Notamment, le nombre et la diversité des impacts attendus, parfois en partie contradictoires (e.g., conservation de la biodiversité et amélioration des moyens d'existence dans les villages), et les capacités locales généralement faibles pour faire respecter les pratiques d'exploitation jugées non durables apparaissent déterminants (Dressler et al. 2010).

D'autre part, les études démontrant la performance écologique de la gestion communautaire sur le maintien des ressources sont rares (mais voir Waldie et al. 2016). Or la littérature disponible sur l'écologie de nombreuses espèces de poissons récifaux suggère que la mobilité

de ces ressources à l'âge adulte affecte la pertinence des mesures de gestion à petite échelle, comme les réserves marines et la gestion communautaire dans son ensemble, dans la mesure où les poissons peuvent franchir les limites territoriales en fonction de leur domaine vital.

Face à ce constat controversé, notre premier cas d'étude a exploré la performance de la gouvernance communautaire des pêcheries récifales au Vanuatu, où les contingences sur les pêcheries récifales s'accentuent comme dans les autres îles du Pacifique (e.g., croissance de la population côtière et de la demande urbaine en produits de la mer, innovations technologiques dans le secteur des pêches, développement des réseaux de transport commerciaux). Deux études complémentaires ont été réalisées dans le cadre d'une recherche-action effectuée de 2010 à 2014 (Tableau1). Chacune fait l'objet d'un chapitre dédié.

Chapitre 1.1 : Exploration des interactions verticales entre les niveaux de gouvernance communautaire et gouvernemental des petites pêcheries

Léopold M., Beckensteiner J., Kaltavara J., Raubani J., Caillon S. (2013). Community-based management of fisheries in Vanuatu : what works ? Marine Policy 42, 167-176.

Dans le chapitre 1, l'analyse a porté sur l'opportunité de développer des interactions verticales entre les niveaux communautaire et gouvernemental de gouvernance. La cogestion des pêcheries est en effet communément considérée comme le mode de gouvernance le plus efficace et équitable pour soutenir des actions collectives et apporter une solution aux problèmes de surexploitation (Sen et Nielsen 1996; Jentoft 2003; Berkes 2010; Guttiérez et al. 2011). Les interactions verticales concernaient à la fois les échelles spatiales (locale / nationale) et les sources d'autorité (coutumière / légale) respectives de ces deux niveaux de gouvernance.

L'intervention a débuté par une analyse du contexte de gouvernance selon une perspective historique. Nous avons étudié comment les niveaux de gouvernance communautaire et gouvernemental interagissaient depuis 1990 sur l'île d'Efaté, où la pression de pêche récifale est la plus forte du pays en raison de la proximité de la capitale Port-Vila (57 000 habitants). Deux sources d'informations ont été mobilisées : i) des enquêtes réalisées auprès de plusieurs catégories d'acteurs locaux dans sept communautés villageoises de l'île, pour recueillir leurs perceptions sur la gestion communautaire des pêcheries, et ii) une revue de la littérature sur des données historiques disponibles sur la gestion communautaire des pêcheries dans ces villages. Les ressources récifales étaient exploitées par quelques dizaines à quelques centaines de pêcheurs opérant à pied ou à partir de petites embarcations, généralement non motorisées.

A partir des données historiques et empiriques recueillies, les trajectoires de la gestion communautaire et les facteurs ayant contribué à leur dynamique depuis deux décennies ont été analysés pour répondre aux questions suivantes :

1) Comment l'homogénéité et l'hétérogénéité des préférences des acteurs locaux affectent-elles la capacité des communautés à réguler les activités de pêche récifale sur leurs territoires maritimes ?

2) Quelles mesures de gestion les communautés sont-elles capables (ou non) de mettre en œuvre à leur échelle locale ?

3) Quels bénéfices sont attendus d'une gouvernance multi-échelle des petites pêcheries récifales ?

Abstract

In the Pacific, coastal communities have compensated for chronically low capacity of governments to manage fisheries by implementing local regulations in their marine tenure areas. In order to investigate the performance of community-based fisheries management (CBFM) in Vanuatu, trajectories and factors of change in CBFM systems since the 1990s were analysed. Focal group interviews were conducted in seven villages on Efaté island in 2011 and supplemented by a review of supporting literature. Results reveal the increasing and excessive reliance of CBFM systems on external agencies that promoted overly complex management plans. Examination of trends in CBFM systems shows that community and national fishing rules that were highly acceptable by local societies were more likely to be enforced in the long run. In particular, the establishment of marine reserves was the most widespread and best enforced community rule for the purposes of conservation, ecotourism, and/or fisheries. Overall, the results challenge the current effectiveness of CBFM in achieving sustainability of reef fisheries in Vanuatu, and highlight the over-reliance on small marine reserves as a management tool. Community initiatives must be strengthened by new specific national regulations governing subsistence and commercial reef fisheries as part of a multi-scale co-management approach.

Résumé

Dans le Pacifique, les communautés côtières ont compensé les faibles capacités des gouvernements pour la gestion des pêcheries par la mise en place de régulations locales dans leurs tenures maritimes respectives. Afin d'étudier la performance de la gestion communautaire des pêcheries au Vanuatu, les trajectoires et les facteurs de changement des systèmes de gestion communautaire des pêcheries ont été analysés depuis les années 1990. Des enquêtes par groupe focal ont été réalisées dans sept villages de l'île d'Efaté en 2011 et complétés par une revue de la littérature disponible. Les résultats ont révélé la dépendance croissante et excessive des systèmes de gestion communautaire des pêcheries vis-à-vis d'agences extérieures, qui promouvaient des plans de gestion généralement complexes. L'examen des tendances des systèmes de gestion communautaire des pêcheries montre que les règles de pêche communautaires et nationales qui étaient les plus acceptées par les populations locales étaient respectées plus durablement. En particulier, la mise en place de réserves marines était la règle communautaire la plus fréquente et la mieux respectée, dans un objectif de conservation, d'écotourisme, et/ou de pêche. Dans l'ensemble, les résultats questionnent l'efficacité actuelle de la gestion communautaire des pêcheries à assurer la durabilité des pêcheries récifales au Vanuatu, et soulignent le fait que la gestion communautaire dépend largement des réserves marines. Les initiatives communautaires doivent être renforcées par de nouvelles régulations nationales spécifiques, gouvernant les pêcheries récifales commerciales et de subsistance dans le cadre une approche de cogestion multi-échelle.

Keywords
Community-based fisheries management; multi-scale fisheries management; near-shore fisheries; fishing regulation; marine reserve; local knowledge

1. Introduction

Market-based factors have encouraged users of rival goods such as common pool marine resources to employ extraction strategies that have led to the general over-exploitation of worldwide fisheries. The decline of a large number of jointly-used fisheries that have been run by top-down government-based fisheries management (GBFM) further suggests that this governance strategy is not particularly effective (Hunt 2003). Calls for a different approach emerged in the late 1980s based on the observation that under certain conditions, users can self-organize to achieve successful governance without individual appropriation of resources (Berkes 1989; Ostrom 1990; Ostrom et al. 1999). It is now well established that the knowledge of local stakeholders can aid in making decisions about the management and the conservation of marine resources (see e.g. in Neis et al. 1999; Berkes 2000; Webb et al. 2004).

An upsurge of interest in community-based natural resources management attempts to address this desirable change in governance and has produced considerable scientific debate (see e.g. in Shackleton et al. 2010). Community-based fisheries management (CBFM) has spread most rapidly in developing countries and particularly in the Pacific, where this system has grown upon a fertile cultural acceptability to reduce the general decline of coral reef resources (Ruddle et al. 1992; Johannes 2002). Similar to GBFM, CBFM regimes may include different regulatory measures such as species and gear restrictions, closed seasons, access rights, and marine reserves (MR). A number of small-scale case studies have established that CBFM may improve the use of local social capital in terms of governance, communication, knowledge, enforcement, cooperation, reciprocity and adaptive capacity (McClanahan et al. 1997; Alcala 1998; Ostrom and Walker 2003; Pretty 2003; Lobe and Berkes 2004; Berkes 2008). External governmental and/or non governmental agencies have also increasingly been associated with CBFM initiatives through collaborative or co-management arrangements (Adams 1998), although the latter operate within the prescribed implementation periods of external projects. CBFM may therefore appear as a powerful, integrated approach to maintain natural ecosystems, benefits to fishers and community livelihoods.

However, biological evidence of the effectiveness of CBFM regulations on fisheries remains scarce. The outcomes of CBFM are context-dependent (see review in Cinner and Aswani 2007) and inconclusive findings challenge the much vaunted intrinsic effectiveness of CBFM in the long term. Among other factors, multiple and often competitive expected outcomes (e.g. biodiversity conservation, local short-term socioeconomic needs, local livelihood improvement) and the lack of local capacity (e.g. social cohesion, leadership, financial resources, linkage with government policies) to control unsustainable uses determine

the organization and success of community-based natural resource management (Dressler and Büsher 2010). These factors may eventually produce disenchantment with CBFM as a viable alternative for local fisheries if management measures do not produce perceived results (Blaikie 2006; Maliao et al. 2009). Time was also found to be a major determinant of success or failure of CBFM because of the dynamics of the local socio-political relationships, fishing activities and environmental factors (Ruddle 1998; Agrawal and Gibson 1999; Aswani 2005). CBFM is highly sensitive to temporal change in the factors mentioned above and should therefore be perceived as a site-specific adaptive process.

The historical and socio-political context in Vanuatu (South Pacific) provides relevant conditions to analyze the functioning of CBFM, since the latter has been fully recognized by national legal and political frameworks. Since the country's independence in 1980, communities have been assisted by the Vanuatu Fisheries Department (VFD), which has provided support to CBFM through programs initially aimed to enhance trochus (*Trochus niloticus)* fisheries (Amos 1995; Johannes 1998a, 1998b). Owing to its limited staff number and financial capacities, the VFD has largely relied on communities and sea tenure to frame and to enforce coastal fisheries management. National fisheries regulations were established in 1982, 2005 and 2009 and mainly affect the commercial sector, i.e., high-value, export and world's flagship species (i.e., marine turtles and mammals). Communities are the legal owners of near-shore resources and generally manage their marine tenure at the community level using locally-specific regimes (Ruddle 1994; Hickey 2007). Across the archipelago, subsistence fisheries extend over about 3,100 km^2 in waters from 0 -100 m depth, and play a key role in this nation's protein supply (Cillaurren et al. 2001). The considerable financial resources invested by the national government through fisheries development programs have had relatively little impact (David and Cillaurren 1992). Fishing for subsistence continues to dominate in terms of number of fishers and marine product consumption, and engages about 50 % of Vanuatu's rural population (Mael 2007). As in other Pacific islands, coastal and urban population growth, technological innovation and improvements of commercial networks have raised near-shore resource sustainability issues and new challenges for CBFM (Johannes and Hickey 2004).

Thirty-one years after Vanuatu's independence, this paper aims to investigate the effectiveness of CBFM and suggest practical management regulations based on community and national governance structures in light of current near-shore fishery challenges. Using empirical case studies and a review of the supporting literature spanning two decades, trajectories in CBFM systems since the early 1990s and factors that have contributed to their dynamics were analysed, including fishery management knowledge among community members and the influence of external agencies on local fishery management.

2. Material and methods

2.1. Study area

The study was conducted in seven rural coastal villages in Efaté island (Fig. 1). In most islands of the archipelago, the poorly developed transport network within and between islands strongly restricts seafood marketing and maintains inshore fishing activities at subsistence level. The context is different on Efaté island owing to the proximity of Port-Vila, Vanuatu's capital (57,000 inhabitants), whose population has more than doubled since 1989 (+4% per year). The presence of good transport infrastructures along the coast allows villages on the island to feed the growing urban demand in marine products. Coastal fisheries are thus exposed to higher risks of overexploitation than in the rest of the country.

In six out of seven villages in the study area, external agencies (e.g. local and international non-governmental organizations (NGOs), cooperation agencies of foreign governments) intervened during the period 2000-2010 as part of development or conservation projects supported by the VFD (Fig. 1). These foreign-funded projects have developed participatory management plans for marine resources at the community level based on local contexts and expectations. Following an ecosystem approach, these plans have implemented numerous actions to limit environmental impacts (e.g. mangrove conservation, waste management, land resource management, ecotourism development), and, in particular, have imposed restrictions on fishing. These plans were created for a period of four or five years after launching ceremonies meant to mark the communities' strong commitment to implement the projects and comply with the management plans.

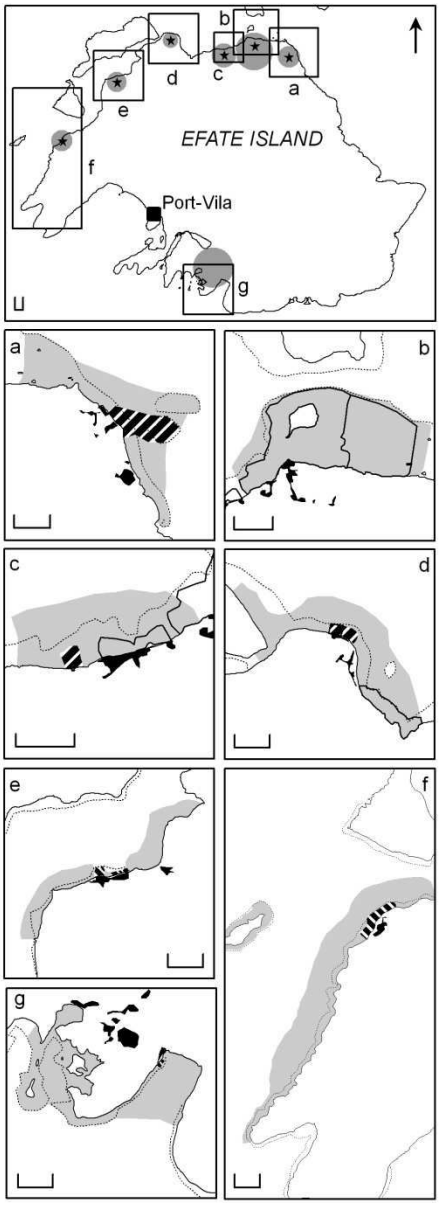

Figure 1. Map of Efaté island (Vanuatu) showing the locations of the seven villages that were studied: Takara (a), Paunangisu (b), Emua (c), Siviri (d), Tanoliu (e), Mangaliliu (f) and Eratap (g). Stars indicate villages that had been assisted by external governmental and non-governmental agencies during the period 2000-2011 with the support of the Vanuatu Fisheries Department. Grey circle: population size (110 to 1350). (b-g) Black area: inhabited area. Grey area: community coastal fishing area. Striped area: marine reserve. Bold line: ex-marine reserve established between 1993 and 2010. Dotted line: reef. Scale bars represent 1 km.

2.2. Data collection by focus-group interviews

In order to collect local fishery management knowledge, semi-structured interviews were conducted using open-ended questions. The surveys covered 1) the sociopolitical and economic context, including local governance, structure of chiefdoms, recent history of settlement, and main sources of household income; 2) the characteristics of coastal fisheries (0 -100 m depth), including the nature and number of fishing gear and boats, target species, catch uses, and spatial data on fishing areas, MRs, and villages' maritime boundaries; and 3) the local management system, including the fishing rules in force for the past 20 years, the presence of informal management committees, the possible contributions of external agencies (e.g. NGOs, government, foreign public institutions), and the perceptions of current issues and suggestions for fishery management. Spatial data were gathered using satellite images

(1:20,000 scale) and participatory mapping (Calamia 1996) and incorporated into a geographic information system.

Local knowledge was collected by interviewing focus groups over a period of five days in each village between April and July 2011 (Krueger and Casey 2000; Le Fur 2011). These small homogeneous groups (3-6 persons) were established, with the help of local leaders, according to common characteristics in age (18-30 years and >30 years), gender and social status. Overall, eight to nine groups were interviewed in each village: 1) the council of the traditional leaders and chiefs; 2) the informal management committee representing key informants on issues related to environment and the management of marine resources; and 3) six to seven groups of active fishers across gender and age categories. In total, 59 groups (234 persons) participated in the survey (Table 1).

In order to supplement interview data on past fishing rules and external intervention, existing literature on local management systems in the survey area was used. Specifically, Johannes and Hickey (2004) recorded the community fishing rules implemented in five out of the seven villages in 1993 and 2001. Unpublished documents on village management plans prior to this study (if any) were also reviewed.

Table 1. Characteristics of the groups of stakeholders interviewed in each of the seven villages visited in this survey (Efaté island, Vanuatu). Chiefs: council of traditional leaders. Management committees: key informants responsible for implementing local management and knowledgeable about issues related to environment conservation and the management of marine resources. Fishers: active fishers according to age and gender categories. The total number of respondents per village is also indicated.

Villages	**Number of survey groups of stakeholders**						**Total**	
	Leader groups		Fisher groups				Survey groups	Respondents
	Chiefs	Management comittees	Men (18-30 yr)	Men (>30 yr)	Women (18-30 yr)	Women (>30 yr)		
Takara	1	1	2	2	1	1	8	29
Paunangisu	1	1	2	2	1	2	9	30
Emua	1	1	2	2	1	2	9	46
Siviri	1	1	1	3	1	1	8	24
Tanoliu	1	2	1	2	1	2	9	40
Mangaliliu	1	1	2	2	1	1	8	29
Eratap	1	0	2	2	1	2	8	36
Total	7	7	12	15	7	11	59	234

2.3. Data analysis

It was assumed that a fishing rule (hereinafter termed "local rule") was in force over the village's marine tenure if it was mentioned either in the literature review or by at least 50% of the surveyed groups of stakeholders, who considered that the transgression of such rules was equivalent to poaching and sanctioned by a community-based or national procedure. Conversely, fishing rules that failed to meet these criteria were considered to not be enforced. The local fisheries regulatory framework was defined by the set of local rules. These included both the community rules set at the village level and the national rules implemented by the VFD.

Local regulatory systems were described for four periods (1993, 2001, 2002-2010, 2011). The survey by Johannes and Hickey (2004) was used to standardize the first two periods across villages. Changes in local regulatory systems over the four periods were investigated in relation to their situation in 1993 following a comparative approach. A multiple correspondence analysis (MCA) was used to study the temporal trajectories and the similarity of local regulatory systems across villages. Local rules were coded in binary form (presence/absence in each village) for the four periods before treatment in the MCA. The MCA was performed using Spad®.

In order to assess the degree of consensus and of social acceptability of management systems, the similarity of local perceptions on coastal resource management between stakeholder groups within and among villages was analyzed. Perceptions on local fisheries issues and suggestions for management were previously classified into thematic categories derived from interview data. Six categories of management issues were defined: high fishing pressure, excessive use of gillnets, small or large size of MRs, poaching from within villages and/or from neighbouring ones, environmental disturbances, and within- and/or between-village social disputes. Nine categories of management suggestions were defined: no management change, local awareness on sustainable management practices, gillnet restrictions, the development of MRs, the periodic harvest of MRs, the establishment of other fishing rules, higher resources for local patrol operations, and the development of alternative sources of income. For each stakeholder group, these categories were then coded in binary form (presence/absence at the interview) and used as qualitative variables. The value of these variables represented the profile of the group's perceptions on local fisheries issues and suggestions for management. Classifications were performed between groups of stakeholders based on their perception profiles using Bray-Curtis similarity index in PRIMER-E© (Clarke and Gorley 2000).

3. Results

3.1. Characteristics of village near-shore fisheries

Population size and growth over the last decade ranged from 110 to 1,350 inhabitants and from 45% to 260% among villages, respectively (Table 2). Overall, fishing capacities also varied greatly among villages, reflecting large differences in their degree of socio-economic dependence on coastal resources (Table 2). Near-shore fishing was practiced mainly on foot or using traditional canoes while the use of outboard-powered boats was limited or nonexistent because of investment and operating costs. The fishing area varied by a factor of five among villages (2.7 to 13.9 km^2) and extended to 0.5 to 1 km offshore of the fringing reef (Fig. 1). The extent of reef and lagoon fishing areas was linked to the geomorphology of marine tenures and varied by a factor 19 among villages (0.4 to 7.6 km^2). Handline was the only fishing gear used by both male and female fishers and was therefore the most common gear in all villages. Catch from handlines was used for consumption by family members. The other two predominant types of fishing gear were gillnets, used as an active or passive technique during day or night respectively, and spearguns, commonly used at night to increase fishing yields and the size of fish caught. These latter two types of gear accounted for most of the catch of each village, for self-consumption and sale in the village, road markets or markets in Port-Vila. Catches of invertebrates (e.g. trochus, giant clams (*Tridacna spp*. and *Hippopus hippopus*), lobsters (*Panulirus spp*.), sea cucumbers (*Actynopyga spp*., *Bohadschia spp*., *Holothuria spp*., *Stichopus spp*., and *Thelenota spp*.)) generally appeared much lower than fish catches, which included a wide variety of reef fishes in proportions that varied across villages, depending on their fishing capacities and marine geomorphology.

Table 2. Characteristics of the seven villages used in this study (Efaté island, Vanuatu): population size, fishing capacities (extent of the fishing area and number of gillnets, spearguns, wooden canoes and motorized fishing boats), and marine reserves (date of creation, status, coastal length and surface). * Paunangisu's marine reserve ended in 2008 and was not in force at time of survey.

Villages	Population [a]	Fishing capacities						Marine reserves			
		Coastal fishing area		Gillnet [c]	Speargun	Canoe	Motorized boat	Date of creation	Status	Linear extent (km)	Area [d] (km²)
		Total (km²)	Reef [b] (km²)								
Takara	320 (+15%)	5.9	3.6 (61 %)	19	9	7	0	2008	temporary (pluriannual)	0.9	1.1 (23 %)
Paunangisu	630 (+13 %)	8.0	7.6 (94 %)	66	15	10	0	2007*	permanent	4.5	6.5 (86 %)
Emua	280 (+23 %)	2.7	1.4 (52 %)	32	9	2	0	2005	permanent	0.3	0.1 (7 %)
Siviri	110 (-45 %)	6.3	3.0 (47 %)	35	12	9	2	2006	temporary (annual)	0.8	0.2 (6 %)
Tanoliu	650 (+260 %)	2.8	0.4 (14 %)	46	21	7	1	1998 2002	permanent permanent	0.5 0.3	0.06 (12 %) 0.05 (10 %)
Mangaliliu	260 (+73 %)	13.9	3.8 (28 %)	15	23	6	3	1990s	temporary (annual)	1.8	0.6 (14 %)
Eratap	1350 (+80 %)	6.6	3.2 (48 %)	200	20	50	3	1990s	permanent	0.2	0.02 (1 %)

[a] In brackets: population growth rate between 1999 and 2009

[b] In brackets: % of total coastal fishing area

[c] 25 m long, 1.5 m to 6 m high, 15 mm to 50 mm square mesh size

[d] In brackets: % of the reef area

3.2. Local fisheries management systems in 2011

Fisheries were managed at the community level under the authority of one or several chiefs depending on the village. The marine tenure was open to all fishers in each village. Twelve fishing rules were in force in at least one village in 2011, including two national rules (found in 100% of villages) and ten community rules (found in 14% to 86% of villages) (Table 3). Finfish fishing appeared unregulated in over 77% to 100% of the villages' reefs and lagoons, i.e., outside of marine reserves except in one village. On the contrary, the commercial sea cucumber and trochus fisheries were effectively regulated throughout the marine tenure of villages by national rules (100% of villages) and by even more restrictive community rules (43% of villages). MR was the most widespread community rule (86% of villages) or even the only one (43% of villages), while temporary closure of fishing for trochus was the second most common community rule (43% of villages).

MRs occupied 0.2 to 1.8 km along the fringing reef and 0.02 to 1.1 km², i.e., 1% to 32% of the villages' reef and lagoon areas (Table 2). Boundaries of MRs were located within 400 m of the most outlying houses and within 500 m from shore, except in one case where a remote reef (700 m from shore) was included (Fig. 1). Seventy-one percent and 29% of MRs were closed permanently or temporarily, respectively (Table 2). In the latter case, the openings occurred once or twice a year for community events (e.g. Christmas, traditional ceremonies, payment of school fees) or after several years of closure. The principal objective of all MRs (as stated by interviewees) was to increase fish and invertebrate resources within the MRs (Fig. 2). The expected benefits varied widely among villages and among stakeholder groups within villages. In particular, the conservation of marine ecosystems, attractiveness to tourists, and benefits to fisheries were the most widely shared objectives, in 60%, 40% and 20% of villages respectively (Fig. 2).

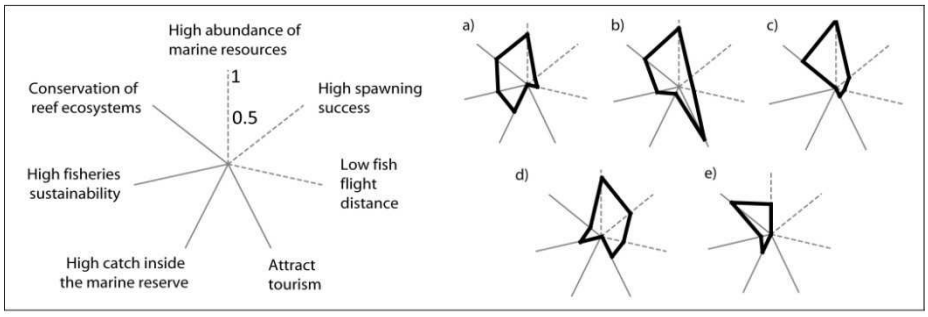

Figure 2. Objectives of community marine reserves in Takara (a), Emua (b), Siviri (c), Tanoliu (d), and Mangaliliu (e) villages in proportion to the number of stakeholder groups. Dotted lines: expected biological effects on resources within the marine reserves. Continuous lines: expected benefits for the community.

Table 3. Local fishing rules in force between 1993 and 2001 in each of the seven villages included in this study (Efaté island, Vanuatu). White circle: community rule in force between 1993 and 2010. Filled circle: community rule in force in 2011. Filled square: national rule in force in 2011 (greensnail *Turbo marmoratus* ban: 2009-2020; ban on sea cucumbers *Actynopyga spp*., *Bohadschia spp*., *Holothuria spp*., *Stichopus spp*., *Thelenota spp*.: 2008-2017; trochus *Trochus niloticus* minimum catch size: 1982). Village-based management plans were implemented in Takara (2008), Paunangisu (2006), Emua (2011), Siviri (2006), Tanoliu (2006), and Mangaliliu (2006).

Local fishing rules	**Villages**						
	Takara	Paunangisu	Emua	Siviri	Tanoliu	Mangaliliu	Eratap
Temporary species bans							
Greensnail*				○		■	
Clamshell	○				○	○●	
Shellfish			●				
Trochus	○		○●	○●		○●	
Sea cucumbers	■	○■	○■	○■	○■	■	■
Lobsters		○					
Coconut crab		○					
Minimum catch sizes							
Clamshell				○			
Shellfish			●				
Octopus	○			○			
Trochus	■	■	■	■	■	■	■
Reef fish			●				
Gear restrictions							
Gillnet mesh size	○	○	●	○	○	○	
Castnet use	○	○	●	○		○	
Hook size			●				
Night spearfishing					○	○	
Total closure							
Marine protected area	○●	○	○●	○●	○●	○●	○●

3.3. Typical trajectory of local fisheries regulatory frameworks from 1993 to 2011

Seventeen local rules were applied in the study area between 1993 and 2011. The most common concerned MRs, the use of gillnets, the use of castnets, and the temporary closure of trochus fisheries (100%, 86%, 71%, 57% of villages, respectively) (Table 3). The main factorial plane of the MCA (48.7% of the total inertia) was structured by the number of local fishing rules, highlighting the complexity of the fisheries regulatory frameworks (Fig. 3). The latter have changed markedly over the past twenty years except in one case (Fig. 3 g). Change in these rules followed a common temporal trajectory in five villages, although the changes occurred at different times in different villages (Fig. 3 a).

Three phases can be identified in this typical trajectory. The first phase was characterized by poorly elaborated local regulatory frameworks and very few local fishing rules. An increase in and a diversification of the local fishing rules occurred during the second phase in the late 1990s (Fig. 3 e) or in the 2000s (Fig. 3 b, d, f, h). Two kinds of actions

particularly contributed to this development: 1) the closure of sea cucumber fisheries, which was temporarily implemented by 2001 in four villages and in 2008 in all villages through enforced national regulation, and 2) the implementation of community management plans that generated local regulatory innovations (e.g. temporary closure of certain species, minimum size limits, restrictions on use of certain types of fishing gear, establishment of MR). The third phase was characterized by an opposite trend marking the continuation of two national rules on sea cucumber and trochus fisheries but the withdrawal of 50 to 100% of community fisheries rules, including gear restrictions, species bans, and minimum size limits (Table 3). Meanwhile, 86% of MRs have been maintained over time despite some change in their size, location or both, and 75% of temporary closures of trochus fisheries were extended or renewed (Table 3). As a result the local regulatory frameworks have become more homogeneous and simpler in 2011, with the exception of the village whose management plan was launched in that year (Fig. 3 c).

The stakeholders' perceptions showed that 54 groups (92% of all groups) have shown concern about the evolution of the state of their coastal fisheries, which have been subjected to different challenges across villages (Fig. 4 a). The most commonly perceived management issue was poaching from within or neighbouring communities due to social disputes or household needs (43% of villages), excessive fishing effort (14%), excessive use of gillnets (14%), within- and between-village disputes (14%), and environmental impacts on marine habitats (14%).

The stakeholders have systematically discussed courses of action to improve the current management arrangements to address issues pertaining to fisheries. The most common suggestion concerned gillnet restrictions (in 43% of villages), the development of MRs (29%), the establishment of other fishing rules (29%), and the development of alternative sources of income (14%). In all villages (25 to 88% of groups), there was expression of willingness to strengthen cooperation with outside agencies to improve the local management system. Points on which cooperation was sought included the nature of the relevant fishing restrictions, the creation of management plans, and the general raising of awareness.

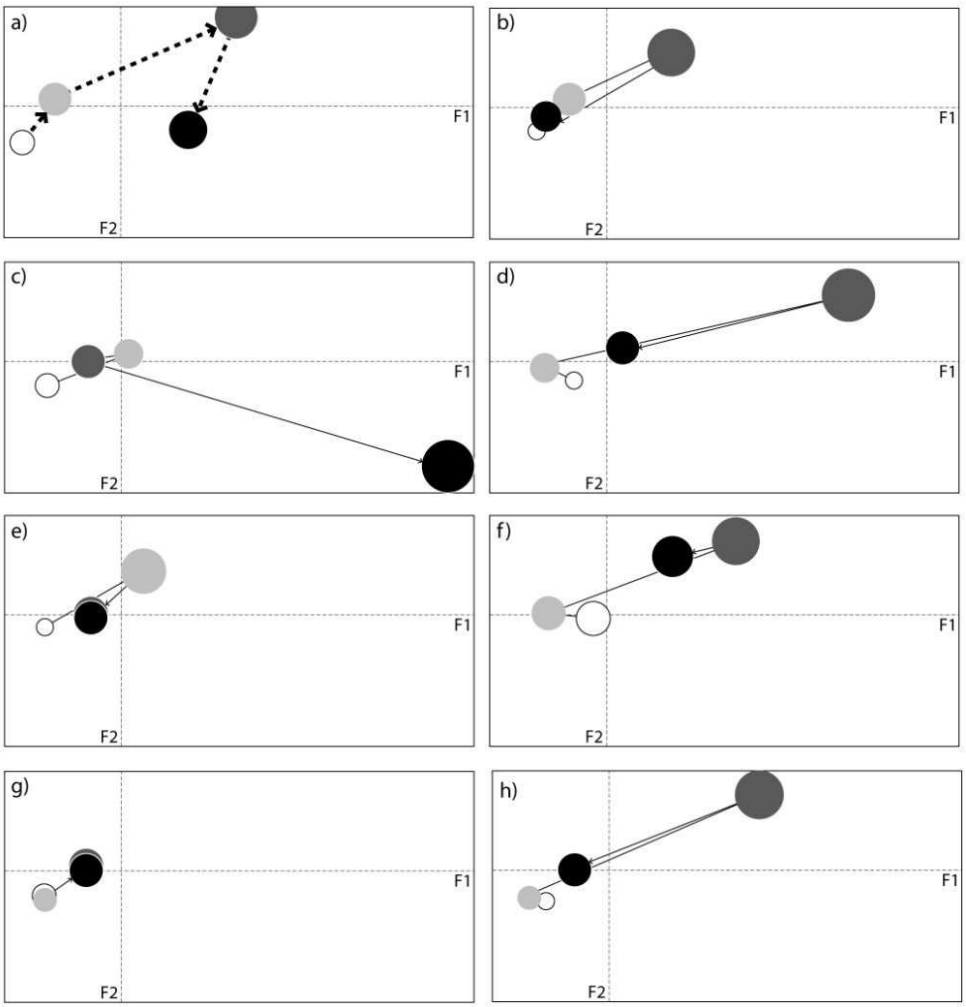

Figure 3. Main factorial plane (axis 1: 32.1% and axis 2: 17.5% of total inertia) of the multiple correspondence analysis performed using the local fishing rules of the seven villages of the study (Spad®). Dotted arrow: temporal pooled village trajectory (a). Arrow: temporal trajectories of Paunangisu (b), Emua (c), Siviri (d), Tanoliu (e), Mangaliliu (f), Eratap (g), and Takara (h) from 1993 to 2011. White circle: 1993. Light grey circle: 2001. Dark grey circle: 2002-2010. Black circle: 2011. Symbol size is proportional to the number of local fishing rules in force in the villages (1 to 9).

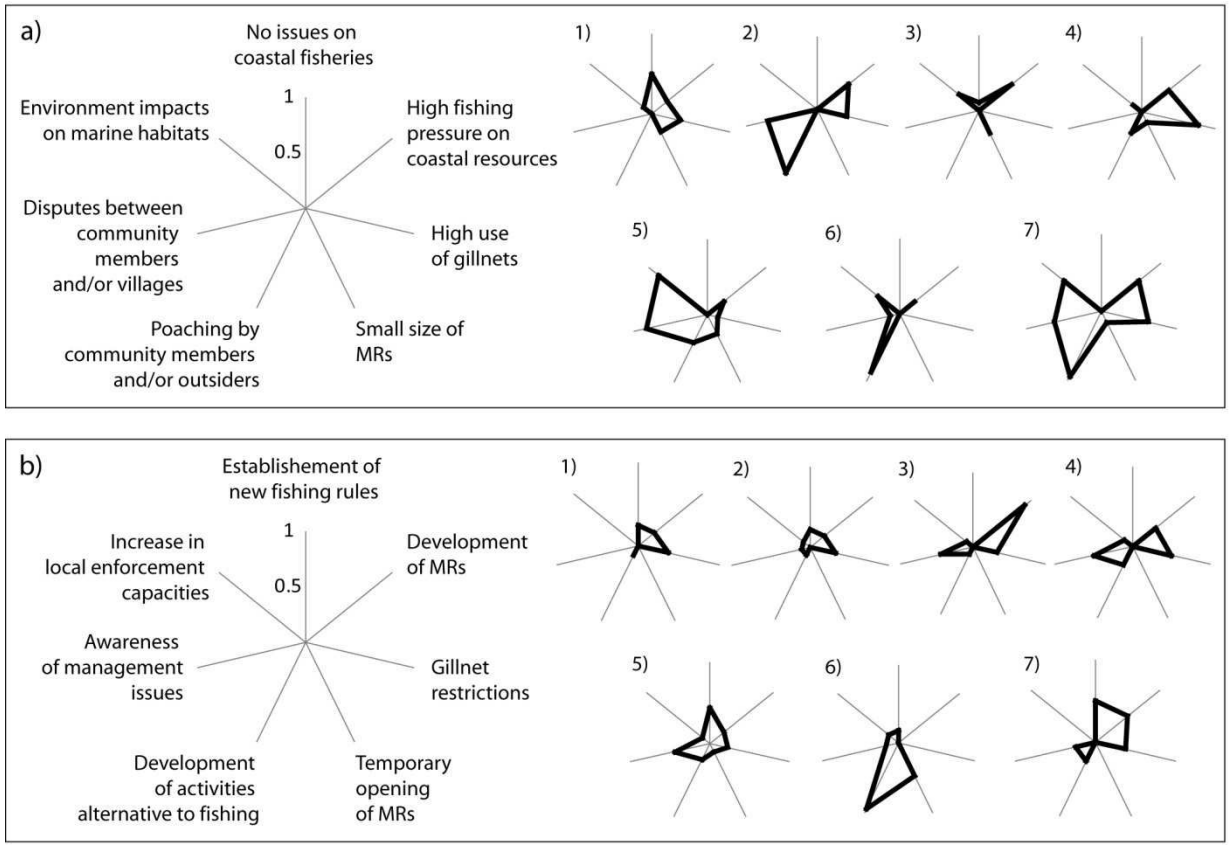

Figure 4. Local coastal fisheries issues (a) and suggestions for management (b) in Takara (1), Paunangisu (2), Emua (3), Siviri (4), Tanoliu (5), Mangaliliu (6), and Eratap (7) villages in proportion to the number of stakeholder groups. MRs: marine reserves.

3.4. Issues and suggestions for fisheries management

The results also showed that 76% and 95% of the fisheries issues and suggestions for management, respectively, were shared by fewer than half of the stakeholder groups from the same village (Fig. 4 a, b). Multivariate classifications confirmed that local perceptions were heterogeneous within villages and that the stakeholder groups did not usually share a similar vision (Fig. 5 a, b). In particular, divergences were frequently observed within villages between leaders and management committees, as well as between these groups and most of the fisher groups, that were grouped in very different classes (except in two cases, i.e., Paunangisu (Fig. 5 a) and Mangaliliu (Fig. 5 b)). Moreover, the classes derived from management issues and suggestions, respectively, joined together very different groups of stakeholders, suggesting that the groups that shared similar views on current fisheries issues expressed different suggestions for management (and conversely).

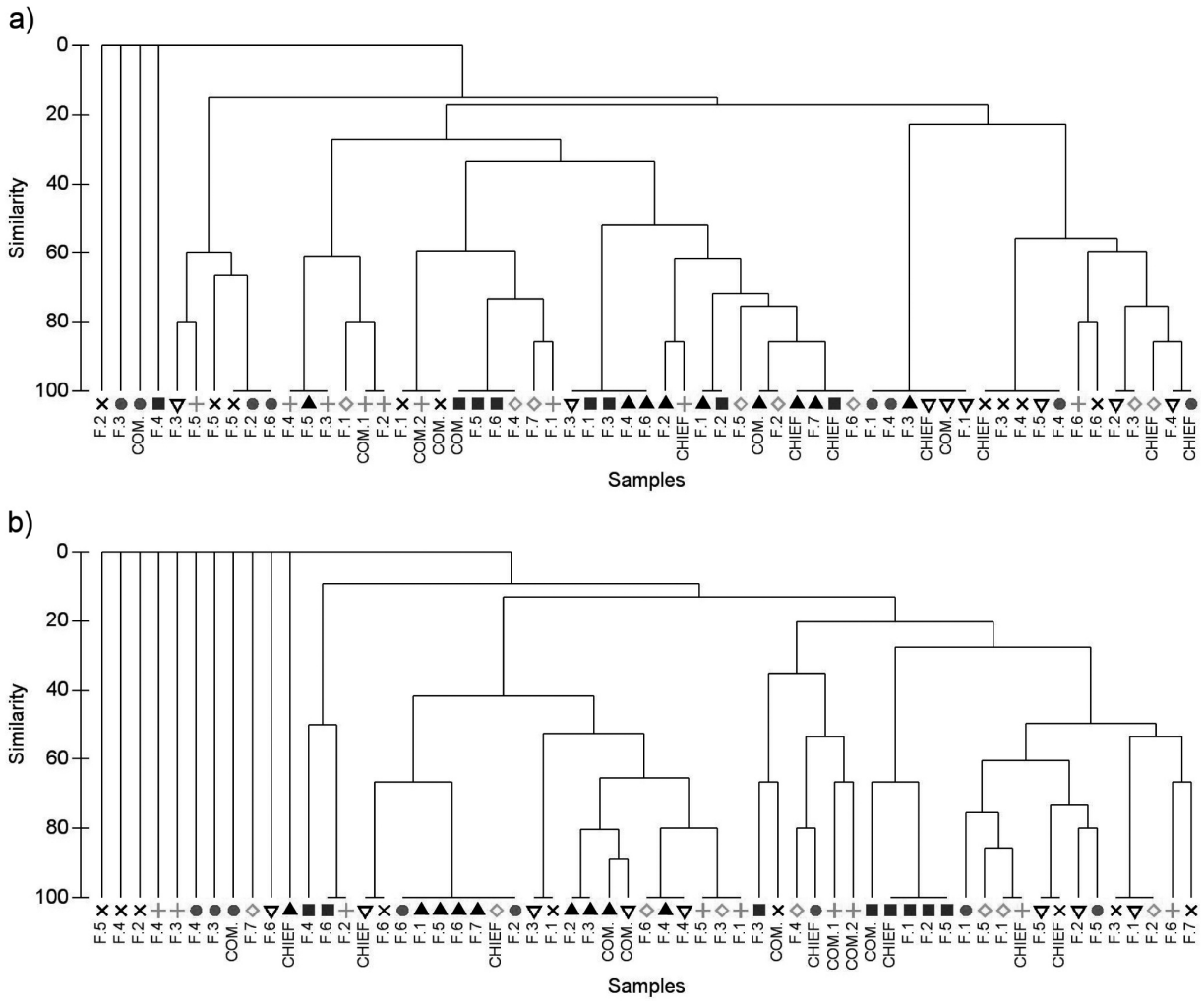

Figure 5. Classification of coastal fisheries issues (a) and suggestions for management (b) using the perceptions of the stakeholder groups of the seven villages of the study (Primer®). CHIEF: council of traditional leaders. COM.#: Management committee for environment. F.#: Fisher group. Circle: Takara. Black triangle: Paunangisu. Cross: Emua. White triangle: Siviri. Plus sign: Tanoliu. Square: Mangaliliu. Diamond: Eratap.

4. Discussion

4.1. Interventionism and sustainability of the fishing restrictions

CBFM of coastal fisheries in Vanuatu combined community and national rules and has followed a trend similar to that observed across the Pacific since the 1990s (Johannes 2002). The growth of community restrictions of fishing activities has been interpreted as a sign of adaptive capacities of the communities of Vanuatu to face the increasing exploitation of resources (Johannes and Hickey 2004). Using data spanning two decades, this study revealed, however, that most community rules were short-lived and that CBFM systems relied on the support of external governmental or non-governmental agencies.

The apparent dynamism of community management in the 2000s was partly exogenous and maintained by the intervention of agencies mobilized by global conservation and sustainable development goals (Hviding 2003; White 2007). These external interventions have greatly influenced the nature and complexity of the local fisheries regulatory frameworks over the last five years through the participatory implementation of management plans. The reasons for the rapid decline in the number of community regulations since around 2007-2010 should be further investigated. In particular, most fishing regulations written into the village-based management plans were given up following the departure of external agencies, despite their ceremonial launching. Although the withdrawal of such rules could come from a perceived lack of the biological effect on the reef fisheries after one to several years, this hypothesis was not supported by interview data. Two other factors have more likely contributed to the disregard of previously declared rules, i.e., disagreement with, and poaching by, neighbouring fishers, and/or divergences within the community itself on the implementation of these rules resulting from the perception that these rules were misaligned with community objectives and concerns. The latter hypothesis cannot be excluded based on the observations of this study, which showed that the perceptions of management issues and strategies often differed among stakeholders, particularly among traditional authorities, leaders and resource users. The management projects initiated by external agencies have likely worked as factors of change of fishing practices and the local governance, generating different visions within the communities and potential sources of conflict (Schoeffel 2007; Wagner 2007). Once external support has finished, the management of these divergences depends on the ability of communities to successfully enforce the new rules, sanction transgressions, and prevent impunity (Cadoret 2009). Alternatively, communities may ease tensions by simply withdrawing the controversial rules. It is remarkable that the withdrawal of community rules has not been formally notified in the community, contrary to their establishment, which was accompanied by ceremony. This suggests that the transgression of these rules has gradually and tacitly become the norm and highlights the dependency on external support to maintain these rules.

The evolution of CBFM systems in the study area since the 1990s therefore suggests that in a context of weak government capacity, the sustainability of local fishing regulations is related to their social acceptability at the community level (i.e., including all social groups). Acceptability is linked to local socio-political and economic mechanisms acting on the opportunity costs, the incentives, and the social and cultural foundations of fishing rules, the analysis of which is beyond the scope of this study (Aswani 2005; Cinner et al. 2007; Hilborn 2007). Those rules that benefit from a social consensus at the community level should be easier to maintain in the absence of external intervention. In the study area, only two community regulations (i.e., MR and the temporary closure of trochus fisheries) and two national regulations (i.e., the moratorium on sea cucumbers and the minimum size limit of trochus) regulations met this criterion. This finding challenges the current performance of CBFM, as only long-term rules are likely to improve resource status in a sustainable way. Moreover, near-shore finfish fisheries were de facto unmanaged outside of MRs in six out of

the seven villages studied, while the resources outside of MRs supported the catch for food and cash income.

4.2. Multi-scale management of near-shore fisheries in Vanuatu

4.2.1. Opening marine reserves to fishing?

The results show that MRs have become an accepted management tool by communities of Vanuatu, as has been noted by other authors (Bartlett et al. 2009) and across the Pacific (Govan 2009). MRs also appear to be adopted as long-term community rules. The diversity of the expected benefits of MRs in the communities has certainly helped to broaden the local social consensus on their establishment (McClanahan et al. 2006). However, 71% of the villages in the study area that established a MR, even of small size, have not introduced any additional restriction on finfish fishing. Owing to the generalization of MRs across the country, if they are to be effective, it thus appears mandatory that they have a real impact not only on conservation but also on the performance of fisheries.

In particular the capacity of periodically harvested MRs for managing reef finfish fisheries looks promising (see review in Cohen and Foale 2013). A growing literature has provided evidence that the maximum catch threshold in such MRs should be adjusted depending on local ecological performance (see e.g. in Cinner et al. 2006; Jupiter et al. 2012) and on the flexibility of fishing activities in the communities (Cinner 2007). For instance, the absolute accumulation of resources in MRs, and therefore the sustainable catch level during openings, is expected to vary proportionally to the size of the MRs (Halpern 2003). A closure-pulse fishing-closure strategy for community MRs should combine effort limitations and output control in the form of a spatial, collective, and multispecies allowable catch. The concentration of fishing effort during very short pulses of fishing events (e.g. several hours) and over the limited space of the MR would allow effective monitoring of fishers, catches, and reliable resource indicators (e.g. size structure of catch, catch per unit of effort). This comparative advantage over other fishing regulations gives temporary community MRs a real capacity to enforce adaptive and sustainable exploitation in these protected areas. Achievement of this goal would likely generate new social and economic incentives, which are considered to be key factors in the success of fisheries management (Hilborn 2007; Gutiérrez et al. 2011). Such incentives may open the way to increasing the size of MRs under CBFM regimes and therefore to better control of overall reef catches.

4.2.2. Strengthening community initiatives through specific national fisheries regulations

Although community temporary MRs appear to be a promising option for management of reef fisheries in Vanuatu, the results highlight the over-reliance of CBFM on this management tool given the current small size of community MRs and the difficulty for

communities to enforce restrictions of finfish fishing outside MRs (Sadovy 2005; Stefansson and Rosenberg 2005). Additional fishing restrictions and increased capacity for enforcement must therefore urgently be encouraged at larger scales. Combining the respective advantages of CBFM and GBFM would increase the capacity of each of these management scales (Cash and Moser 1998). Providing institutional support for rules that enjoy widespread acceptance at the community level would likely contribute to achieving this objective, while taking into account the variability of local social and ecological contexts. Based on this empirical study on Efaté island, two new national fishing regulations could be considered based on the most common community rules. The first measure would establish village-based temporary closures of trochus fisheries at the national scale to strengthen community control over catches and sales on the long run (Ruttan 1998). This approach has been adopted by the VFD to manage sea cucumber fisheries and could be extended to trochus fisheries, which have similar sedentary characteristics. This approach would also facilitate implementing catch quotas for each village in the main production sites, a measure recommended for effective management of trochus fisheries more than twenty years ago (Nash 1990). The second measure would consist in restrictions on fishing gear, primarily on gillnets, due to their high fishing efficiency. Such restrictions have indeed been implemented in 86% of the studied villages, but are barely enforced by the communities themselves, although their positive effects on reef fisheries have been established (see e.g. in Hicks and McClanahan 2012). Regulating the importation and sale of certain types of fishing gear (e.g. nets of small mesh size) at the national level seems the most effective way to reduce the use of these types of gear throughout the country at reasonable control costs. The two proposed national regulations would be both relatively simple for government to enforce and difficult for communities and fishers to circumvent, which would improve their management performance. Following repeated requests from a local NGO and communities, the VFD is also currently developing a legal framework to empower local wardens to better enforce existing and future national fishing regulations.

5. Conclusion

This study suggests the need to move from an idealized conception of CBFM to an operational stage that includes evaluation of the performance of CBFM regimes and of the types of external support that are most appropriate (Lane and McDonald 2005; Wilson et al. 2006). In particular, providing external assistance for tools of high social acceptability and supporting local needs would very likely prove more effective in achieving sustainability of fisheries than short-lived generic approaches derived from conservation, ecosystem management and participatory models (Sadovy 2005; Blaikie 2006; Dressler and Büsher 2010).

Although the survey results should be validated on other islands before being generalized, they stress the need for proactive engagement of public authorities in managing coastal fisheries. Such intervention is critical to strengthening the commitment of

communities and, conversely, to enforce minimum fishing restrictions in areas where communities have not set up their own rules. The State must exercise its fundamental responsibility to ensure the sustainability of uses of the environment, including subsistence activities and coastal fisheries in particular [39]. Co-management innovations between government and local communities are still needed, to optimize the design and the implementation of effective fishing regulations of coastal fisheries in the country over the long term.

Acknowledgements

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Chapitre 1.2 : Exploration des interactions horizontales structurant la gouvernance des pêcheries récifales entre les communautés villageoises

Léopold M., O. Chateau, H. Gabriault, J. Ham, S. Andréfouët, J. Raubani, P. Dumas (2017). Fish movements within community-managed fishery reserve networks: an acoustic survey of Lethrinus harak *in Vanuatu. Marine Ecological Progress Series 571: 153-168.*

Dans le chapitre 2, nous avons évalué dans quelle mesure l'échelle communautaire de gestion est adaptée à la dynamique spatio-temporelle des ressources récifales mobiles, comme les poissons, exploitées à des fins de subsistance et de vente locale. Spécifiquement, les résultats du chapitre 1 ont été approfondis par une analyse de l'efficacité écologique des réserves marines communautaires temporaires, institution ayant montré l'acceptation sociale la plus durable et la plus large dans les communautés villageoises de notre cas d'étude, à l'instar de nombreux pays du Pacifique. Les réserves marines communautaires sont par ailleurs identifiées comme des instruments capables de favoriser les initiatives de cogestion (Pomeroy 2003).

Une étude participative par marquage acoustique a été réalisée entre 2011 et 2014. Le marquage acoustique de poissons est une méthode de plus en plus utilisée pour étudier la connectivité entre zones récifales, en particulier entre des réserves marines et les zones exploitées voisines. Nous avons étendu cette méthode aux territoires maritimes de plusieurs villages situés au nord de l'île d'Efaté.

Les déplacements de plusieurs espèces de poissons exploités ont été étudiés pendant une durée de 10 à 12 mois consécutifs lors de deux campagnes successives : le suivi a d'abord porté sur une espèce de Lethrinidés en 2011 et 2012 dans trois villages étudiés dans le cadre du chapitre 1 (11 km² de zone de pêche, 64 habitats coralliens différents), puis sur cinq espèces de Scaridés et Acanthuridés en 2013 et 2014 dans cinq villages. Seul le premier suivi fait l'objet de ce chapitre. Les questions posées étaient les suivantes :

1) Quelle est la mobilité spatio-temporelle de l'espèce ciblée en fonction de la mosaïque d'habitats de la zone d'étude ?

2) Quelles sont les effets de la localisation et des dimensions des réserves marines sur leur efficacité potentielle ?

3) Quelle est l'échelle spatiale de gestion des ressources de poissons récifaux appropriée à leur domaine vital ?

Ce travail constitue à notre connaissance la première étude du lien entre la mobilité des ressources et les interactions socio-spatiales (horizontales) dans un contexte de gestion communautaire.

Abstract

Acoustic telemetry has been increasingly used for monitoring fish movements at different spatial and temporal scales. In this study passive telemetry and fine-scale habitat data were integrated for the first time to investigate the relevance of community fishery reserves (CFRs) for managing reef fish resources. In Efaté Island (Vanuatu) 38 thumbprint emperors *Lethrinus harak* (Lethrinidae) were tagged at seven sites and tracked between April 2011 and February 2012 using an acoustic array of 16 receivers. The survey area extended over 11.3 km² of fringing reef in three coastal community tenures that included three small CFRs. Habitats were mapped using very high resolution satellite imagery and ground-truthing. Thirty fish were detected for up to 229 days (median = 153 days). Six geographical groups were identified among 21 resident fish. These groups showed strong fidelity to small sites (116-763 m) that were located in reserves and fished areas, across community tenures, and across 11 habitat types. Overall 42 excursions were detected at several hundreds to thousands of meters from the fidelity sites along contiguous fringing reefs, across habitat types, and across boundaries of CFRs and community tenures. The estimated home range size of *L. harak* ranged from 116 m to 3980 m (median: 763 m) and was highly varied within fish groups. We concluded that home range size and behavioral plasticity of *L. harak* limit the effectiveness of small individual CFRs for protecting this species. Networks of CFRs would be more effective but require management arrangements between neighbor communities.

Résumé

La télémétrie acoustique est utilisée de plus en plus fréquemment pour suivre les déplacements de poissons à différentes échelles temporelles et spatiales. Dans cette étude, pour la première fois, la télémétrie passive a été intégrée à des données à fine échelle sur l'habitat marin pour étudier la pertinence des réserves marines communautaires pour gérer les ressources de poissons récifaux. Sur l'île d'Efaté (Vanuatu), 38 empereurs de l'espèce *Lethrinus harak* (Lethrinidés) ont été marqués dans sept sites et suivis entre avril 2011 et février 2012 grâce à un réseau acoustique de 16 hydrophones ancrés. La zone de suivi s'étendait sur 11.3 km² de récifs frangeants dans la tenure maritime de trois communautés comprenant trois petites réserves marines communautaires. Les habitats récifaux ont été cartographiés en utilisant une image satellitaire à très haute résolution et des données de vérification sur le terrain. Trente poissons ont été détectés jusqu'à 229 jours (médiane = 153 jours). Six groupes géographiques de poissons ont été identifiés au sein de 21 poissons résidents. Ces groupes montraient une forte fidélité à des sites de faible étendue (116-763 m) qui étaient localisés dans les réserves et les zones exploitées, dans les trois tenures maritimes, et dans 11 types d'habitats. Au total 42 excursions ont été détectées à plusieurs centaines ou milliers de mètres des sites de fidélité le long de récifs contigus, à travers différents types d'habitats et à travers les frontières des réserves marines et des villages. L'étendue estimée du domaine vital de *L. harak* était comprise entre 116 m et 3980 m (médiane : 763 m) et variait largement au sein des groupes de poissons. Nous concluons que l'étendue du domaine vital et

la plasticité comportementale de *L. harak* limite l'efficacité des petites réserves marines communautaires individuelles à protéger cette espèce. Des réseaux de réserves marines communautaires seraient plus efficaces mais nécessitent des arrangements de gestion entre communautés voisines.

Keywords
Acoustic telemetry, fish movement, community-managed area, fishery reserve, Lethrinus harak, Vanuatu, coral reef

1. Introduction

In small Pacific countries, culture-based sociopolitical organization, remoteness of coastal populations, land dispersion, and limited human and financial governmental capacities have favored community-based initiatives for regulating reef fishing practices (Ruddle et al. 1992, ; Ostrom et al. 1999; Johannes 2002). Taboos have traditionally enforced local, village-specific, harvest restrictions (e.g. species and gear bans) and area closures within marine tenures. The latter raise very specific issues compared to westernized, permanent no-take zones and are used by communities as fishery management tools (Sale et al. 2005). Firstly, closed areas are usually used as marine fallow areas: they are temporarily opened and harvested periodically to address communities' or fishers' socioeconomics needs rather than long-term ecosystem conservation objectives (Cohen and Foale 2013; Cinner et al. 2006). Net biomass exports from such community fishery reserves (CFRs) therefore occur through larval dispersion and spillover of juveniles and adults as well as through direct, occasional outputs by fishers during openings. Secondly CFRs are necessarily embedded in marine tenures, thus limiting in effect their potential size which is typically one to two orders of magnitude smaller than that of westernized no-take zones (Foale and Manele 2004). Size of CFRs is particularly critical for managing mobile species threatened by fishing because closures efficiently protect those fish that spend most of their time within the reserve boundaries (Kramer and Chapman 1999).
Positive effects of CFR on the abundance of exploited reef finfish and invertebrates have been documented both directly and indirectly within these reserves, through underwater observations of resource density (e.g. Léopold et al. 2009, Dumas et al. 2010) and through catch and fishing yield monitoring during the reserve openings (e.g. Jupiter et al. 2012, Cohen and Alexander 2013), respectively. These positive ecological effects and short-term fishing benefits explain the general acceptability of CFRs among fishers and coastal communities (Johannes 1998b, Bartlett et al. 2009) and, consequently, the upsurge of conservation programs in the Pacific since the 1990s. During the last decade hundreds of small CFRs (< 0.1-1 km^2) have been established in the South Pacific, most often with the support of local and national governments and/or international organizations (Alcala and Russ 2006, Govan 2009). These small CFRs are better enforced locally and last longer than other community-based fishing restrictions, particularly for reef finfish (Léopold et al. 2013a).

Surprisingly, despite the enthusiasm that they have generated locally and regionally in the Pacific, little field information is available on the ecological mechanisms that determine the effects of CFRs on reef resources (but see Waldie et al. 2016). This knowledge would be extremely valuable for promoting effective reserve designs, and also for providing sensitive explanations and avoiding the disillusionment of local communities in case of reserve failure. Conversely, the literature on westernized, permanent no-take zones is informative despite the knowledge gaps on the interactions between CFRs and reef resource space uses. A large number of acoustic surveys have shown that differential mobility of adult reef fish very likely impacted on no-take zone effectiveness because of spillover effect (e.g. Meyer et al. 2007; 2010, Chateau and Wantiez 2008,; Marshell et al. 2011). Acoustic telemetry has been increasingly used in the last decade for assessing site fidelity behaviors among reef fish, daily and migratory movements, home range size and shape, and habitat uses patterns (e.g. Marshell et al. 2011; Zeller and Russ 2011; Bijoux et al. 2013; Currey et al. 2014; Garcia et al. 2014b; Matley et al. 2015). Several authors have also documented the effects of habitat structure and diversity on fish movements and discussed the expected outcomes of no-take zones (Hitt et al. 2011; Pittman et al. 2014). Whether or not these findings could be extrapolated to CFRs in the Pacific context needs to be investigated due to their specific characteristics.

Following other acoustic studies concerning the connectivity between no-take zones and neighbor areas, this paper presents one of the first acoustic surveys conducted in community-managed marine areas in the Pacific. This survey was part of an action research program aimed at improving coral reef fishery management in Vanuatu (southwest Pacific). Specifically both passive telemetry and fine-scale habitat data were jointly used to empirically investigate the relevance of CFRs for managing reef fish resources. In Vanuatu current national fishing regulations target high-value commercial species such as invertebrates (i.e. lobsters, trochus, sea cucumbers) and are less concerned with reef finfish species that are used for own-consumption and local markets. The implementation of small CFRs has therefore been widely promoted by the Fisheries Department since the 1990s as a way to protect and stockpile reef resources for the benefits of local communities (Hickey and Johannes 2002). In this study, we acoustically monitored the movements of the thumbprint emperor *Lethrinus harak* (Lethrinidae), a species targeted by near-shore fishers throughout Vanuatu (Amos 2007). Fish response to a reefscape mosaic, closed areas and community tenures was investigated. Results allowed us to make recommendations on the size and location of CFRs within communities' marine tenures. Management perspectives based on home range analysis are discussed for designing effective individual CFRs and CFR networks according to space use patterns of *L. harak* and marine tenure.

2. Materials and methods

2.1. Fishing and management context in Efaté Island, Vanuatu

In Vanuatu, most of the population lives in rural coastal areas and engages in small-scale fishing activities (VNSO 2007). Strong geographical variations in fishing pressure are observed throughout the archipelago according to natural conditions (e.g. reef geomorphology, habitat diversity) and socioeconomic factors (e.g. transport infrastructures, commercial networks, urban demand for fish and demographic pressure) (Cillauren et al. 2001). Owing to the proximity of Port-Vila, Vanuatu's capital, near-shore finfish resources are exposed to greater sustainability issues on Efaté Island than in the rest of the country.

The survey was conducted on Efaté Island over a relatively large reef area (11.3 km^2) that encompassed three villages' tenures, namely Emua, Paonangisu and Takara, totaling ~1,200 inhabitants (Figure 1a). Environmental conditions, fishing status and management regimes differed among villages (Léopold et al. 2013a, Table 1). Paonangisu village was characterized by the largest reef fishing grounds, population level, and subsistence and commercial fishing pressure, which yielded higher socioeconomic needs and fishery dependence than the other villages. No community-based fishery management rule was enforced in this village due to sociopolitical conflicts that undermined local governance efficiency. However fishers perceived a decline in reef resources early on and proposed the implementation of a shoreline-bounded CFR. The planned CFR is adjacent to the most populated area of the village to facilitate permanent visual surveillance and discourage poaching (Figure 1a). Community reliance on reef fishing for their livelihoods was higher in Paonangisu village than in Emua and Takara villages. The two latter communities had established a well-enforced shoreline-bounded CFR for several years and some other temporary local fishing restrictions were effective at the time of this study (Figure 1a). Although fishers mentioned that fish abundance within both CFRs had increased they questioned the adequacy of its dimension and location.

The three communities were strongly involved in, and supportive of, the acoustic survey since it was expected that the results would provide crucial information to support local decisions related to the use of CFR for the management of coral reef fisheries within their respective marine tenure.

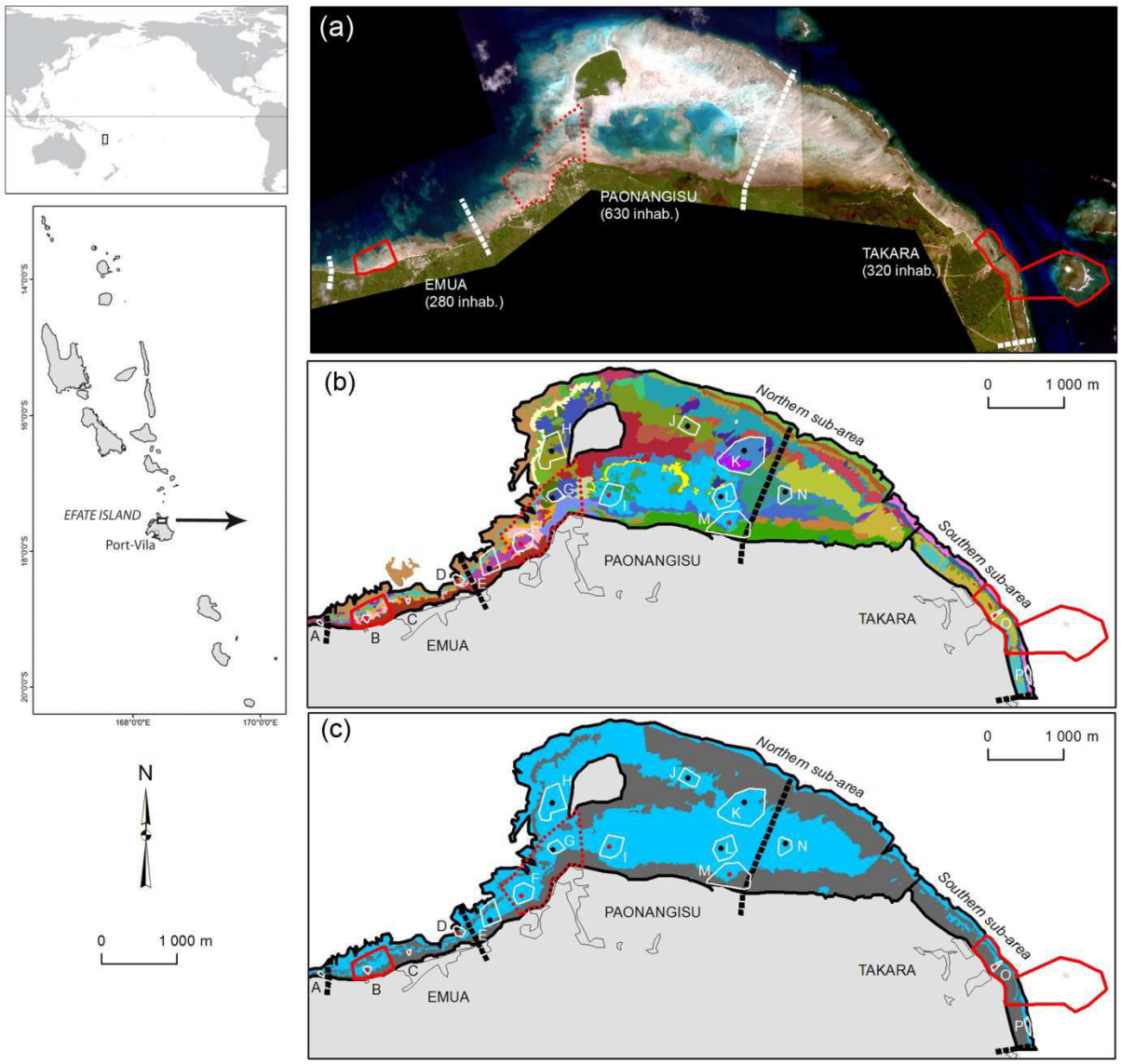

Figure 1. Location of the study area off the northern coast of Efaté island, Vanuatu. Worldview II satellite images (a), habitat map (b), and intertidal areas (c, in dark grey) of the reef system. White polygons (b, c) represent the detection range of each acoustic receiver (n = 16, A to P). The location of the seven fishing and releasing sites of tagged fish (b, c) are indicated by red spots (receivers B, C, D, F, I, M, and O). The thick dotted lines represent the marine tenure boundary of each of the three villages. The thick solid polygon lines represent the boundary of both study sub-areas. The red solid and dotted polygon lines represent the boundary of the existing and planned community fishery reserves, respectively.

Table 1. Characteristics of the three villages in this study (Efaté island, Vanuatu): population size, reef fishing grounds (coastal length, surface, and marine habitats), fishing capacities (number of gillnets, spearguns, and wooden canoes), and marine fishery reserves (date of creation, coastal length, and surface).

Villages	Population	Reef fishing grounds				Fishing capacities			Fishery reserve		
		Linear extent (km)	Area (km²)	Main habitats (% area)	Habitat types (n)	Gillnet*	Speargun	Canoe	Date of creation	Linear extent (km)	Area (km²)
Emua	280	2.1	1.4	Fringing reef (70%) Outer reef (30%)	7	32	9	2	2005	0.55	0.15
Paonangisu	630	4.1	7.6	Fringing reef (54%) Outer reef (23%) Lagoon (12%) Seagrass bed (11%)	44	66	15	10	2016**	1.14	0.66
Takara	320	4.9	3.6	Fringing reef (87%) Outer reef (13%)	11	19	9	7	2008	0.94	0.81

* 25 m long, 1.5 to 6 m high, 15 to 50 mm square mesh size.

** Paunangisu's fishery reserve was planned and not in force at time of survey.

2.2. Fine-scale habitat mapping

The marine area was composed of 1-6 m deep lagoons (1 km²), 0.5-2 m deep fringing reefs (8.3 km²), and a 0.5-10 m deep outer slope (2 km²) representing the main coral reef geomorphologic unit of the island. The limit of the intertidal area was mapped using GPS. It includes 4.9 km² of reef crest and near-shore seagrass beds and reef flats, and accounted for 43 % of the study area (Figure 1a).

A habitat map of the study area was created from two very high spatial resolution (2 m) multispectral Worldview 2 images acquired on 11/07/2010 and 21/08/2010. Images were processed and photo-interpreted according to the user's flow chart described in Andréfouët (2008) to ensure high accuracy and a high number of classes, including a sun-glint correction following Hochberg et al. (2003). Ground-truth was conducted in November 2010 and May 2012 on 77 stations distributed across the study area. Stations were selected using the satellite image to cover the range of color and texture visible on the image. Vertical photographs were used to measure percent cover in algae, seagrass, live coral, dead coral, broken branching coral, sand, rubble and rock (old eroded coral substrate). The habitat map was vectorized and imported into a geographical information system (GIS). The habitat polygons were then used to document the movements of fish between habitat patches.

The habitat map included 64 habitats (surface area in the range 0.01-0.26 km²) defined according to categories and relative size of cover, geomorphology and exposure to wave action (Figure 1b). The composition and spatial distribution of the habitat patches rendered the reef heterogeneity and habitat patchiness. The survey area was composed of two sub-areas characterized by different environmental conditions. The northern sub-area (93.5 % of the survey area) showed high complexity and low-to-medium exposure to wave action. The

southern sub-area (6.5 % of the survey area) was composed of an elongated, shallow reef flat highly exposed to wave action and broken by a 1-6 m deep and 50 m-long channel (Figure 1a,b). Sub-areas were separated by a narrow 120 m-long reef flat exposed to strong tidal currents and swell.

2.3. Receiver array

Passive acoustic telemetry was used to monitor fish movements. A discontinuous array of 16 omnidirectional receivers (Vemco VR2W, 69 kHz) was deployed in strategic locations in the survey area, 14 in the northern and two in the southern sub-areas, at distances exceeding 300 m in most cases (Figure 1c). The deployment of receivers between sub-areas was proportional to the surface of each sub-area. As compared with the only other passive acoustic survey of *Lethrinus harak* (Taylor and Mills 2013), the array design allowed for detecting medium-distance and long-distance fish movements whereas most short-distance movements (< 300 m) remained undetected. Receivers were moored at 0.5-5 m depth, facing upwards.

The detection range of each receiver was empirically tested in similar meteorological and tidal conditions to account for spatial variability in acoustic signal transmission due to marine habitat structure (Marshell et al. 2011, Welsh et al. 2012). Starting at each receiver, a coded V8-4L Vemco (69 kHz, 1 s delay) transmitter was towed along five to eight transects at a constant speed of 1 m s^{-1} in the water column at a height of ~1 m above the sea bottom to mirror the behavior of *L. harak*. The transmitter position was monitored every second by a handheld GPS unit. The position of the last transmitter detection logged by the hydrophone on each radial was used to estimate the detection range of the hydrophone on this radial. A detection polygon was then created for each receiver by joining the most distant detection points in a GIS. Very high variation in detection range was observed (18-370 m) among radials and among hydrophones according to reef habitats and depth. Detection zones varied by two orders of magnitude among hydrophones ranging from 2,630 m^2 to 219,230 m^2 (median: 3,580 m^2) (Figure 1b,c). The overall coverage of the acoustic array represented 8.6 % of the marine survey area (i.e. 17.6 % of the area submerged at very low tide). Because range tests were done only once and control tags were not used, we did not assess potential change in the shape and/or surface of the estimated detection zones in relation to temporally variable environmental conditions (e.g., tidal current, wave action, weather conditions).

Individual detection zones were overlaid on the habitat map in a GIS. The receiver deployment strategy aimed to maximize the diversity of the dominant habitat types covered in the southern and northern sub-areas, given the available number of receivers and their site-specific detection range (Table 2). The detection range of all acoustic receivers covered 21 different habitat types, that altogether represented 72 % of the study area. Individual detection zones included one to four habitat types (≥ 10 % cover) (Table 2, Figure 1b). We assumed that detection zones covered similar habitat types when these habitat types covered more than 50 % of the surface of the detection polygons.

Table 2. Habitat types covered by the receiver array as derived from very high spatial resolution (2 m) multispectral Worldview 2 imagery and underwater ground-truth. Geomorphology, exposure to wave action and dominant substrate cover are indicated. Habitat cover (> 10 %) is indicated in brackets for individual receivers (A to P, see Figure 1).

	Habitat types							Coverage of receivers	
	ID	Geomorphology		Exposure	Dominant cover	Surface	Intertidal zone	Total	Receiver ID
		Large scale	Local scale			(m²)	(%)	(%)	(% detection zone)
Southern sub-area	1	Oceanic-exposed fringing	Reef flat	High	Pavement, rubble	18536	72	7	O(15)
	2	Oceanic-exposed fringing	Reef flat	High	Hard bottom, algae	42936	-	2	O(11)
	3	Oceanic-exposed fringing	Reef flat	High	Hard bottom, coral	29148	-	7	O(24)
	4	Oceanic-exposed fringing	Forereef sand pool and chanels	High	Sand, rubble	179856	-	2	O(34)
	5	Oceanic-exposed fringing	Upper forereef	High	Hard bottom, pavement, coral	323552	-	4	P(99)
Northern sub-area	6	Lagoon-exposed Fringing	Terrace	Low	Sand, seagrass	612924	98	11	M(47)
	7	Lagoon-exposed fringing	Reef flat	Low	Hard bottom, coral cover (< 5%)	300264	-	6	M(11)
	8	Enclosed lagoon	Lagoon floor	Low	Sand, rubble, algae (< 10%)	65492	-	24	I(24)
	9	Enclosed lagoon	Lagoon floor	Low	Sand, rubble	892452	-	18	I(72), L(94), M(33)
	10	Oceanic-exposed fringing	Terrace	Medium	Sand with small coral colony, algae (< 15%)	468796	-	9	J(100)
	11	Oceanic-exposed fringing	Terrace	Medium	Sand, rubble, scattered coral colony,	423088	-	36	K(64), N(44)
	12	Oceanic-exposed fringing	Terrace	Medium	Sand, rubble, hard bottom, scattered coral colony,	361952	-	7	N(56)
	13	Oceanic-exposed fringing	Terrace	Medium	Sand, algae (< 50%)	59212	-	91	K(25)
	14	Oceanic-exposed fringing	Terrace	Medium	Sand, rubble, algae (< 20%)	236652	-	33	H(73)
	15	Oceanic-exposed fringing	Reef flat	Medium	Rubble, hard bottom, sand, algae (< 20%)	316928	-	11	G(76), H(16)
	16	Oceanic-exposed fringing	Reef flat	Medium	Hard bottom, rubble, algae (< 60%), scattered corals	61196	-	13	G(18)
	17	Oceanic-exposed fringing	Reef flat	Medium	Rubble, sand, seagrass & algae (< 50%)	467048	97	2	A(43), C(44)
	18	Oceanic-exposed fringing	Reef flat	Medium	Rubble, sand, algae (< 50%)	221484	-	33	A(56), B(89), F(60)
	19	Oceanic-exposed fringing	Reef flat	Medium	Rock, rubble, algae (< 20%)	153332	-	12	C(56), F(26)
	20	Oceanic-exposed fringing	Escarpment	Medium	Rock, algae & corals (< 5%)	346284	99	4	D(24), E(16)
	21	Oceanic-exposed fringing	Forereef, low relief	Low	Rock (70%), rubble, dead coral (10%), corals (< 5%)	2564988	-	1	D(67), E(17)

2.4. Fish tagging

Lethrinus harak (Lethrinidae) was selected based on ecological and fishing criteria. This ubiquitous species commonly visits a wide diversity of coral reef habitats over coastal reefs, lagoons, mangroves, channels and seagrass inshore areas (Carpenter and Allen 1989, Laroche et al. 1997, Unsworth et al. 2009, Kimirei et al. 2010). Personal underwater observations conducted prior to the acoustic survey confirmed that *L. harak* was present over the whole survey area. Moreover *L. harak* was regularly caught by the entire local fishing community regardless of age, gender and gear (i.e. gillnet, seine, castnet, handline, speargun). This commonly targeted species provided an excellent opportunity to involve local communities and to maximize the chance of local appropriation of the results.

Fish (n = 38) were tagged with acoustic transmitters between May and August 2011. Fish were caught, tagged and released in small groups (3-7 fish) in seven sites corresponding to different habitat types and fishing contexts (Figure 1b,c). These sites were close to receivers to increase detection probability given the anticipated site fidelity behavior of *L. harak* (Ebisawa and Osawa 2009, Taylor and Mills 2013). Fish were caught using harmless techniques (i.e. barbless hooks or non-entangling nets) during daylight hours and stored for 1-2 hours in an aerated 100 L container. Then they were anesthetized in a 20 L container filled with a 0.2 mL L-1 sea water solution of clove oil. Fish were removed after 30-120 s according to opercula and fin movements. A 1 cm incision was made anterior of the anus to insert a V8-4L Vemco transmitter (69 kHz, 210 days battery life, 90 s ± 40 s delay for the first 60 days, 240 s ± 70 s delay afterwards in order to prolong battery life), sterilized in ethanol absolute,

into the peritoneal cavity. The incision was then sutured. Once the harmless surgical procedure was completed (5-9 min), the fish were measured, gently transferred into a recovery cage at sea for two hours to check for post-operative mortality and then released at fishing sites if normal swimming behavior returned (Thorsteinsson 2002). Overall post-operative survival rate was 95 %.

The receivers logged the presence of individual fish (i.e. transmitter code, date, and time) passing within their detection zone from May 2011 to June 2012. Acoustic data was downloaded on a monthly basis.

2.5. Data analysis

Detection data obtained for each individual fish was analyzed to characterize the temporal and spatial mobility, home range and overall reef use patterns of *L. harak*. Detection data during the first 24 h following tagging were excluded from analysis given that tagged fish may exhibit aberrant movements immediately after release (Zeller 1997, Chateau and Wantiez 2008, Marshell et al. 2011). Individual detections were regrouped in hourly bins corresponding to each hour of the day. We assumed that a fish whose presence was logged by a receiver during any hourly bin spent that hour in the detection zone of this receiver. Since the preliminary analysis of detection data revealed that the difference in signal delay across the survey period did not affect fish detection rate, all detection data during both time periods (i.e., during the first 60 days and afterwards) were pooled.

In order to assess the similarity of movement patterns among fish, each individual fish was characterized by its presence (in hourly bins) on each receiver. A non-linear multidimensional scaling ordination (n-MDS) and hierarchical cluster analysis was then performed in PRIMER-E© to identify potential geographical groups of *L. harak* in the area. A geographical group included those fish that displayed similar detection patterns within the acoustic array. The presence of geographical groups on each receiver was mapped as a proportion of their total presence using bubble plots to display the overall distribution of movements of each group. Non-detection periods were not considered in this analysis.

In order to investigate fish response to the reefscape mosaic, presence of marine reserves and community tenures, a series of variables was estimated from acoustic data for individual fish and geographical fish groups. These variables are described here below.

The total detection span of each fish was defined as the difference in date between its release and its last detection logged by the receiver array. A residency index was estimated by the number of days a fish was detected within the acoustic array relative to its total detection span. This index was used for identifying resident and non-resident fish within the acoustic array.

Movement patterns and home range were then described for the resident fish. The home range of a fish was defined as the area in which it spends the majority of its time and engages in most of its routine activities including foraging and resting (Kramer and Chapman 1999;

Botsford et al. 2009). Home range is typically composed of a fidelity site (i.e., core area) and excursion site(s) that are visited occasionally (Chateau and Wantiez 2007, 2008).
In this study, site fidelity was measured by the number of hours a fish was detected in the proximity of a receiver as a proportion of the total number of hours this fish was detected within the array (i.e., non detection periods were not considered). A high value of this index (i.e., close to 1) was indicative of a fish exhibiting site fidelity. Excursions from fidelity sites included travel to, and residency at, destination sites (Chateau 2008). The number, monthly rate, distance, duration, and swimming speed of excursions were calculated for each fish living within a home range. Although it is unlikely that a fish swims in a straight line without stopping, swimming speed was used to detect peculiar (e.g., fast) movements.
Linear measurements of home range and fidelity sites were also provided to characterize fish movements. Maximum linear fidelity site size was estimated as the maximum dimension of the corresponding receiver detection zone. Maximum linear home range size was defined as the longest distance moved by resident fish within the array during their total detection span. It was estimated as the maximum linear dimension of the fidelity site for fish detected by a single receiver, and as the minimum linear distance between the two most distant receivers' detection zones for fish detected on multiple receivers (Chateau and Wantiez 2007, 2008; Meyer et al. 2010). The effect of fish size on home range size and swimming speed was investigated using the Spearman rank coefficient test. Difference in residency, home range size, and excursion distance of individual fish among geographical fish groups was investigated using the non-parametric Kruskal-Wallis test. Reef habitat utilization by individual fish and geographical groups was examined in terms of diversity of potentially-used habitat types and the number of habitat patches in their home range.
Diurnal and nocturnal movements of *L. harak* were investigated by plotting individual detections against time of the day across the whole detection period.
Finally cross-boundary movements through community fishery reserves and marine tenures were characterized (i.e., distance traveled, frequency and duration) for all individual fish and geographical groups.

3. Results

Tagged fish size ranged from 162 mm to 320 mm FL (Table 3) encompassing the maturity size of *Lethrinus harak* (210-220 mm FL; Kulmiye et al. 2002, Ebisawa 2006). Overall, 30 fish (79 % of tagged fish) were detected within the acoustic array. Total detection span ranged between 1 and 229 days (median: 153 days) (Table 3).

3.1. Behavior types

Two behavior types were identified. The first behavior type related to nine fish (170-280 mm FL) that did not exhibit site fidelity. For these fish, residency was low and detection was occasional within the array (< 69 hourly bins detected), which indicated that they were

probably not resident within the monitored area thus precluding a detailed analysis of their movements (Table 3). Four of these fish undertook between-receiver movements over 160-1200 m distances across multiple habitat types whereas the presence of the five other fish was sporadically localized by one single receiver. The maximum linear dimension of the spatial domain used by each individual non-resident fish ranged from 182 m to 1988 m (median: 390 m).

The second behavior type related to the remaining 21 detected fish (170-320 mm FL) that displayed restricted movements within a home range. Total detection span and residency index within the acoustic array ranged between 24 and 229 days (median: 163 days) and between 0.27 and 0.99 (median: 0.73) among these fish. Their presence exceeded 80 hourly bins except for one fish (Table 3). These fish were considered resident within the survey area, even if 4,239 non detection periods (lasting up to 45 days, median: 4.3 h) were observed overall. Home range size and reef use patterns were then further analyzed for these fish.

Table 3. Summary of detection data and movement characteristics of non-resident *Lethrinus harak* tagged in Efaté Island, Vanuatu. Minimum, maximum and median (inter brackets) values are indicated for individual fish detected in each village. See Figure 1 for receiver ID and Table 2 for habitat type ID.

	Emua village	Paonangisu village	Takara village	All
Number of tagged fish	1	7	1	9
Fork lenght (mm)	245	170-280	240	170-280 (241)
Total detection span (day)	227	2-205	1	1-227 (61)
Total presence (hourly bins)	69	1-46	3	1-69 (15)
Movement patterns				
Maximum linear dimension (m)	1205	386-1988	182	182-1988
Receiver ID	D,E,F	E G H I J K M	O	D E G H I J K M O
Habitat types (ID)	19-21	6-11,13-16,20,21	1-4	1-4,6-11,13-16,19-21
Cross-boundary movements				
Fishery reserve	0	2	0	0-2
Village's tenure	1	0	0	0-1

3.2. Home range and movement patterns of resident fish

Resident fish were categorized into six geographical groups (Figure 2). Residency was broadly similar among geographical groups (KW test, $p = 0.11$) although the statistical power of the test was reduced by the small group sizes (1 to 5 individuals).

The home range of *L. harak* comprised a fidelity site and usually one or several excursion sites. We present fidelity site characteristics first. In each group, site fidelity of individual fish ranked above 0.89, showing a marked site fidelity behavior to a single receiver ($n = 20$) or two receivers located at a 370 m-distance ($n = 1$) (Table 4). Fidelity sites extended over 116-386 m (except for one fish: 763 m; median: 227 m), and did not overlap among fish geographical groups. They were located in different environmental, fishing and management contexts over the entire survey area. Specifically fidelity sites were observed in the three community tenures, in marine reserves and fished areas, and in seven habitat types (Figure 3,

Tables 2 and 4). Most fish were caught for tagging on their fidelity site. However, for three fish belonging to three different groups, fidelity sites were located at a 60-800 m distance from the catching sites, suggesting that they had been caught and tagged during excursions.

Home range of neighbor or widely-distant geographical groups partly overlapped due to fish excursions from fidelity sites, except TA1 group (Figure 3). Maximum linear home range size ranged from 116 m to 3980 m (median: 763 m) among tagged fish. Most of them (n = 14, 67 %) resided in ≤ 1340 m-wide areas while one-third of the fish (n = 7, 33 %) resided in areas ≥ 1780 m (Table 4). However, within geographical fish groups, the estimated home range size varied by one order of magnitude among individual fish. This suggested that space use patterns were highly variable even in the same reef area. Maximum linear home range size was not significantly different among geographical groups (KW test, p = 0.07) and not correlated to fish size (Spearman rank test, p = 0.23). However these tests were possibly insufficiently powered to detect true effects of group and/or size due to small sample size.

Habitat-use patterns did not reveal significant habitat preferences for *L. harak*. Tagged fish were detected in 16 and four habitat types in the northern and southern study sub-areas, respectively, including hard and soft bottoms, seagrass beds, and areas partly covered with rubble, algae and/or corals (Table 4). These habitat types represented 66 % and 28 % of the surface of each sub-area, respectively. Visited habitat types were partly specific to geographical groups (Table 4) and varied among fish within these groups except in PA2 and TA1 groups.

In each fish group except TA1, between one and four fish (n = 10 in total, 63 %) occasionally moved out of fidelity sites (i.e. 1 to 5 times per month), totaling 42 detected excursions. Although detection data did not allow for statistical analysis of the spatial and temporal characteristics of excursions, marked differences in fish movements were observed. Travel distance and excursion duration ranged from 160 m to 3400 m (median: 2130 m) and from 7 h to 29 days (median: 18 h). Tagged fish moved to, or undoubtedly crossed, several different habitat types during 71 % and 29 % of detected excursions, respectively. They visited up to seven different habitat types per excursion including hard and soft bottoms, seagrass beds, and areas partly covered with rubble, algae and/or corals. Excursions were unidirectional in three geographical groups, producing elongated activity spaces that followed reef geomorphology outlines, and multidirectional in other groups (Figure 3). No excursions were detected between the northern and southern sub-areas suggesting a limited degree of connectivity between these reef areas.

Swimming speed ranged between 0.1 and 28 m min^{-1} (median: 2.6 m min^{-1}) among 134 between-receiver movements, suggesting that most of these movements were not linear. Interestingly, long-distance (2130-3400 m), fast-swimming (18-28 m min^{-1}) excursions of three mature fish (23-28 cm FL) from the same geographical group were repeatedly observed by the same receivers. These specific movements occurred around new and/or full moon over three to five lunar cycles between August and December 2011.

Diurnal and nocturnal detection patterns of *L. harak* within home range showed that 24-hour activity patterns were widely variable among resident fish (Figure 4). These patterns were not

clearly associated with any particular receiver or geographical group, suggesting that their cause was multifactorial.

Table 4. Summary of detection data and movement characteristics of resident *Lethrinus harak* tagged in Efaté Island, Vanuatu. Minimum, maximum and median (inter brackets) values are indicated for each geographical fish group. See Figure 1 for receiver ID and Table 2 for habitat type ID.

	Geographical groups of resident fish					
	Emua village	Paonangisu village				Takara village
	EM1	PA1	PA2	PA3	PA4	TA1
Number of tagged fish	5	5	1	2	3	5
Fork lenght (mm)	182-280 (250)	170-322 (265)	260	280-321 (300)	272-298 (292)	221-262 (250)
Total detection span (day)	91-218 (187)	108-210 (163)	225	178-211 (195)	42-169 (138)	24-229 (113)
Total presence (hourly bins)	241-3383 (779)	24-343 (112)	258	635-1130 (883)	101-285 (262)	91–1284 (224)
Residency index	0.42-1 (0.99)	0.07-0.61 (0.37)	0.53	0.73-0.88 (0.80)	0.40-0.88 (0.41)	0.34-0.96 (0.80)
Home range						
Maximum linear dimension (m)	116-3979 (3258)	307-3011 (1068)	513	386-1173 (780)	763-2702 (1343)	182
Fidelity site (receiver ID)	B	F	G	I	L & M	O
Habitat types (ID)	14-21	8-10,15,16,18,19	14-16	8,9,14,15	6,7,9,11-13	1-4
Site fidelity index	0.94-1	0.9-1	0.99	0.99-1	0.95-0.99	1
Fidelity site linear dimension (m)	116	307	227	386	763	182
Number of excursions	0-13	0-2	1	0-1	0-3	0
Excursion distance (m)	521-3398	534-1008	286	787	157-562	0
Excursion duration (h)	7-263	24-124	81	92	18-48	0
Maximum swimming speed (m/min)	2.3-28.0	1.1-2.6	0.1	1.8	5.4-13.0	
Non-detection periods						
Number	119-718	15-236	169	250-324	65-160	50-379
Mean duration (h)	2-44	21-263	31	10-17	15-24	5-53
Cross-boundary movements						
Fishery reserve	0-11	0-1	1	1	0	0
Village's tenure	0-11	0	0	0	0-1	0

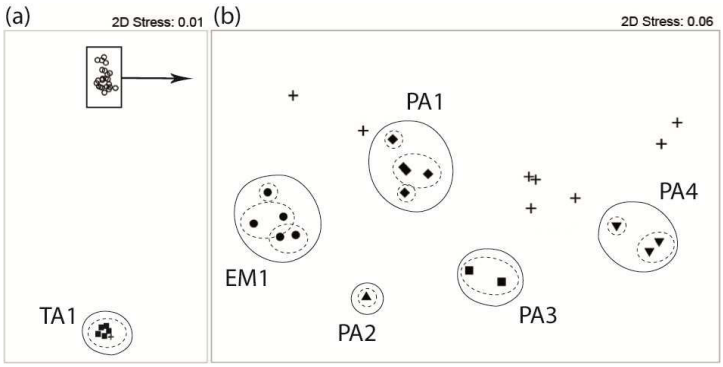

Figure 2. Non-metric multidimensional scaling ordination of space use by *Lethrinus harak* in the whole study area (a) and in the northern sub-area (b). Two behavior types corresponding to non-resident fish (crosses) and resident fish (squares) were observed. Geographical fish groups derived from hierarchical cluster analysis are indicated (EM1, PA1, PA2, PA3, PA4, TA1). Solid and dotted lines represent envelopes of 30 % and 60 % similarity clusters, respectively.

3.3. Cross-boundary movements

Four geographical fish groups (EM1, PA1, PA2, and TA1) were strongly resident within a single CFR of the survey area (Figure 3, Tables 3 and 4). The linear extent of Emua, Paonangisu, and Takara villages' CFRs was 0.5, 1.6, and 1.3 times larger than the median home range size of *L. harak* as estimated by this survey, respectively.

Despite the observed fidelity behavior, fish movements suggested some degree of connectivity of *L. harak* population between CFRs and between villages' tenures in the survey area. On the one hand, a total of 34 outward, eastward excursions (6 to 13 per fish) were recorded for four out of five fish of EM1 group during the survey period. During 21 of these unidirectional excursions, fish would have undoubtedly crossed Emua village's boundary that was located 1500 m from their fidelity site. They were detected both within (15 excursions lasting 8 to 58 h each) and beyond (six excursions lasting 9 to 21 h each) the Paonangisu village's proposed CFR. No inward movement of other tagged fish was observed into Emua village's reserve.

On the other hand, two out of six fish in PA1&PA2 groups were detected outside the Paonangisu village's proposed CFR and during a single excursion each. These excursions lasted 82 h and 120 h and were recorded on the same receiver located 220 m northward of the reserve's boundary. A fish belonging to PA3 group was also detected on this receiver during a single excursion that very likely crossed the proposed CFR.

Lastly, a non-resident fish and two resident fish from PA4 group moved across villages' boundaries on a single occasion, i.e. two from Emua village's tenure to Paonangisu village's tenure and from the latter to Takara village's tenure, respectively.

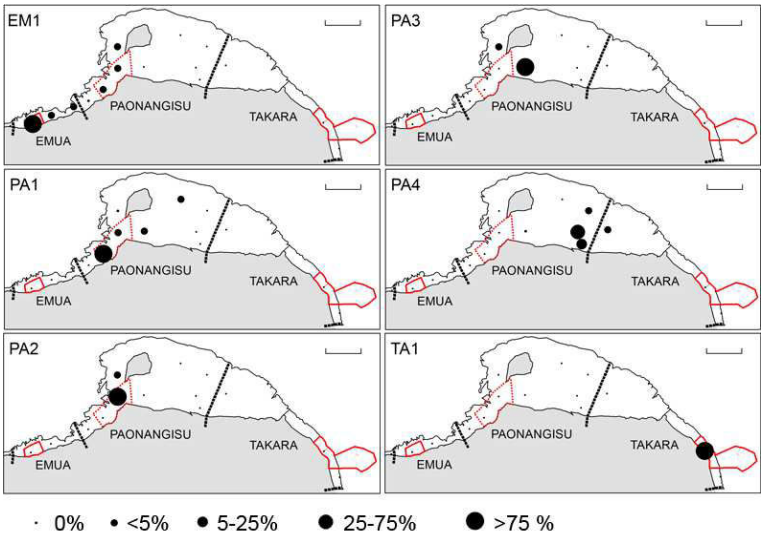

Figure 3. Spatial distribution patterns (bubble plots of hourly detection bins) of each geographical group of *Lethrinus harak* in the study area. The thick dotted lines represent the marine tenure boundary of each village. The red solid and dotted polygon lines represent the boundary of the existing and planned community fishery reserves, respectively. The scale bar represents 1 km.

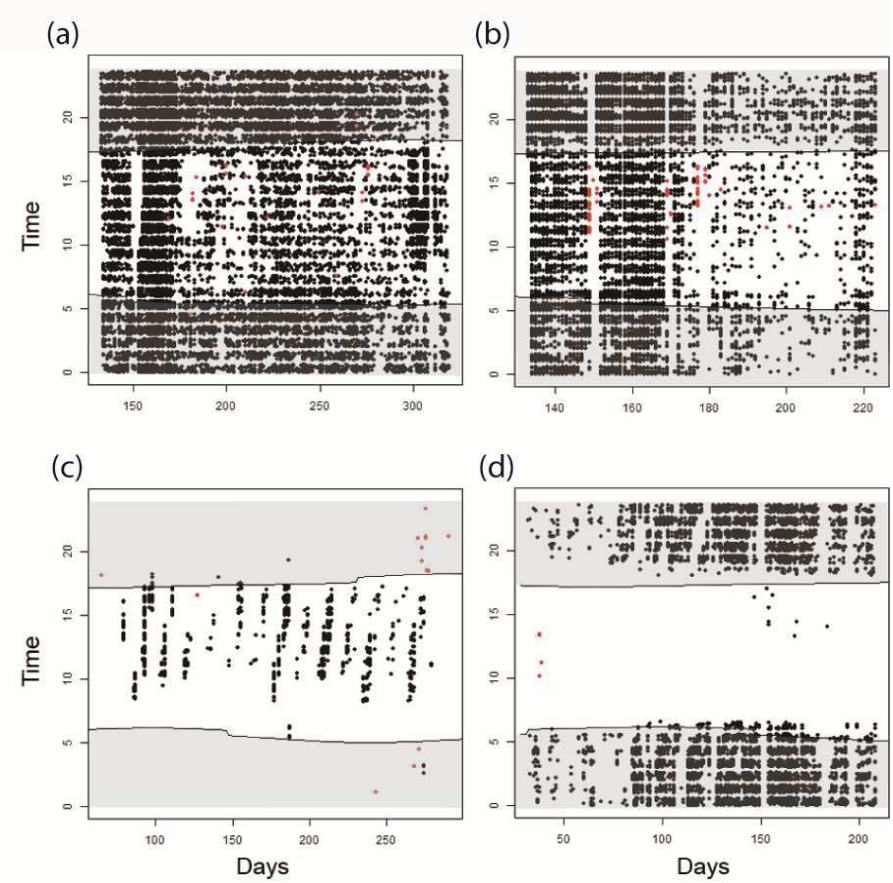

Figure 4. Detection patterns of four individual fish of *Lethrinus harak* from EM1 (a, b, c) and PA3 (d) geographical groups during daytime and nighttime (in grey shade) periods.

4. Discussion

4.1. Non-detection periods and uncertainty of home range estimates

Non-detection periods are inherent to passive acoustic telemetry of marine fishes as a result of receiver-to-receiver gaps, receiver detection range and transmitter delay. Accurate monitoring of home range utilization requires continuous acoustic coverage by receiver arrays with the appropriate spacing and scale (often over several km distances). In practice however, an ideal design is difficult to achieve because of inherent trade-offs between spatial extent, resolution and number of available receivers in passive telemetry surveys (Sale 1998). These trade-offs may lead to underestimating fish home range (e.g. Meyer et al. 2010; Bijoux et al. 2013; Currey et al. 2014; Pittman et al. 2014) since most movements outside the array remain unknown. For example, our results indicate that short-distance (< 160 m) and short-time (< 7 h) excursions of *L. harak* were not captured during this survey because the receivers were positioned too far apart.

Non-detection periods may be attributed to temporally variable environmental factors obstructing acoustic signal transmission within the array, and to fish movements into non-detection zones. For instance, excursions from the fidelity site by TA1 group's fish were not detected, possibly due to the low mobility of these fish and/or the low coverage of the acoustic array in the southern study sub-area. Similarly, the non-resident fish might live within home ranges whose core areas could be located within non-detection areas. This hypothesis is supported by detection data showing that the movement scale of non-resident fish was of the same order of magnitude of that of resident fish. If one assumes that the 4,239 non-detection periods recorded for resident fish in this survey correspond to movements into non-detection areas, this would imply that only 2 % of their true excursions were effectively detected. Given that swimming speed estimates indicated that *L. harak* may operate 1.1-1.7 km-long movements within one hour, resident fish would have been able to move over several kilometers during most non-detection periods. Our estimates of home range dimension should therefore be interpreted conservatively since they were based only on presence data within a discontinuous receiver array.

4.2. Excursions and home range size

This study confirmed that, in Vanuatu, *L. harak* lives within a home range in the same was as has previously shown in Japan (Nanami and Yamada 2009) and Guam (Taylor and Mills 2013). Site fidelity behavior and excursion movements have been documented among a wide variety of reef fish species using passive telemetry. Results consistently emphasize non-uniform space use over short- (i.e., hours) to medium (i.e., days and weeks) time frames (Holland et al. 1996; Zeller 1997; Bellquist et al. 2008; Chateau 2008; Mason and Lowe 2010; Marshell et al. 2011).

Our results also highlighted the high variability of home range dimension among conspecifics inhabiting the same reef areas (i.e., 116 to 3980 m), as already reported for other fish species (Chapman et al. 2012) and commonly observed in taxonomically diverse natural populations (Wilson et al. 1994). However the spatial, temporal and individual drivers of mobility patterns of *L. harak* remain difficult to explain. Excursions over hundreds to thousands of meters have commonly been documented among coral reef fishes in response to exploratory, circadian and spawning factors, among others (Lindholm et al. 2006; Chateau and Wantiez 2008; Meyer et al. 2010; Currey et al. 2014; Matley et al. 2015). In this study, the periodically detected long-distance (> 2 km), fast-swimming movements for three tagged fish (EM1 geographical group) based upon the detection patterns were consistent with those previously described during monthly spawning migrations of *L. harak* (Carpenter and Allen 1989; Taylor and Mills 2013). This suggests that transient spawners undertook regular spawning trips in the survey area at the beginning of the summer season, probably within small groups and spread over several sites since large aggregations of *L. harak* were not reported by local fishers. Spawning migrations from fidelity sites have also been documented for *L. miniatus* (Currey et al. 2014)

and a large variety of reef fish species (e.g., Chapman et al. 2012; Claydon et al. 2012; Nanami et al. 2014).

Home range size of *L. harak* was found to be consistent with that of other lethrinids (Kaunda-Arara and Rose 2004; Currey et al. 2014). However it was larger than the home range size previously estimated for this species by Nanami and Yamada (2009) and Taylor and Mills (2013) using active tracking and passive telemetry, respectively. Additionally, unlike Taylor and Mills (2013), we did not find any positive correlation between fish size and home range estimate. Several authors also observed that fish size and home range dimension of lethrinids (Matley et al. 2015) and other reef fish species (e.g. Bellquist et al. 2007; Alfonso et al. 2011; Marshell et al. 2011) were not systematically correlated (but see Nash et al. 2015).

These different findings partly arose from the differences in home range estimation methods. In order to meet the correct conditions for using statistical home range estimation methods, the acoustic survey must be appropriately designed (Laver and Kelly 2008). Specifically kernel density estimation (Worton 1989) has been extensively used in acoustic studies for estimating home range of reef fish such as *L. harak* (Taylor and Mills 2013) but was inappropriate in this study due to the strong spatial heterogeneity of detection patterns of tagged fish (Downs et al 2012).

Instead we considered all recorded excursions from fidelity sites to estimate the home range maximum linear dimension of *L. harak* (e.g. Meyer et al. 2010) including hypothetical spawning migrations to nearby areas, which might have resulted in overestimating the home range size of this species. Indeed, regular, directed long movements of fish to transient spawning sites are usually considered to be migrations outside the home range of participating fish (e.g., Taylor and Mills 2013; Green et al. 2015). Nevertheless we argue that our home range estimates are appropriate for quantifying the spatial scale of fish movements that is relevant for management (Pittman et al. 2014; Matley et al. 2015; Waldie et al. 2016), which was the main objective of this study.

4.3. Habitat-use patterns and management implications

4.3.1. Effectiveness of temporary closures

This study describes the response of a *L. harak* population to the habitat mosaic, in terms of i) fish residency in habitat patches, ii) movements within- and between-habitats and iii) linear range of movements.

The results indicate that space use patterns alter the potential effectiveness of small CFRs to act as refuges for this species. We observed that site fidelity behavior was consistent across geographical fish groups, reef habitats, and fishing status. The results suggest that small sub-populations of *L. harak* reside within non-exclusive home ranges commonly extending over ≤ 1.3 km. This study therefore suggests that this species could benefit from small spatial refuges (i.e., ~2-km wide), as already found by Taylor and Mills (2013). However, *L. harak* did not exhibit significant habitat preferences although outer reefs were less frequently used than the

reef flat area. The ability of fish to swim across multiple reef habitats increases travel distances, home range size and habitat connectivity at the scale of one to several kilometers, which increases exposure to fishing. Fish mobility across many habitat types consequently undermines the potential ability of small individual CFRs to protect this species (Kramer and Chapman 1999).

CFRs that do not encompass home range of target fish cannot significantly limit spillover, which compromises their effectiveness. As demonstrated by our survey, typical shoreline-bounded CFRs (i.e., hundreds of meters wide) in Vanuatu are expected to better protect the small contingent of the population that use very small, reserve-centered home range. Such small CFRs may therefore contribute to increase the abundance of these sedentary fish within their boundaries during closure as commonly observed within small no-take zones (DeMartini 1993; Halpern 2003) and reported by local fishers during our program. However this sedentary contingent of fish becomes temporarily vulnerable to fishing during periodic openings of CFRs, particularly as the harvest may be very intensive. Given that the rest of the fish residing within CFRs may be caught during outward excursions or spawning migrations, the entire fish population of CFRs may consequently become accessible to fishers at one time or another. Although this may be of short-term benefit with regard to the social acceptability of CFRs within communities, they raise serious resource sustainability issues and question the use of CFRs as a management tool.

Unless harvesting conditions within CFRs are linked to fish reef uses, reserve size and location issues then there may be unrealistic expectations about CFRs being able to sustain surrounding fisheries. To balance the trade-off between fishery yield and biomass buildup it is suggested that only CFRs that encompass the home range size and suitable habitats of a significant part of the target fish population may be harvested during short and controlled openings (e.g. Takara and Paonangisu villages' existing and planned CFRs in this study). CFRs that do not meet this condition should be permanently closed in order to limit fishery outcome to spillover only as in permanent no-take zones (e.g. Emua village's CFR in this study).

Despite our results being specific only to *L. harak*, communities may consider that large CFRs can protect a wider range of species and habitats than small ones, although reserves cannot be of optimum size for all target species in coral reef fisheries (Sale et al. 2005). The use of small no-take zones should also be considered in specific locations that are critical for the development of focal species (e.g., spawning and resting sites, juvenile nurseries). These ecological considerations should be integrated in the local decision-making process when setting CFR boundaries. This is not an easy task as it also necessitates taking into account other critical factors such as the local power relations, the cohesion of the community, ownership issues between communities, and the subsequent distribution of expected socioeconomic benefits (Cohen and Steengergen 2015).

4.3.2.Encouraging networks of community fishery reserves

Large-scale networks of no-take zones are increasingly promoted for achieving both conservation and fisheries management objectives (Gaines et al. 2010). Our results further argue for creating networks of CFRs that account for fish movement patterns and local tenure, particularly in those areas where implementing sufficiently large CFRs is locally unacceptable (e.g., in small community marine areas) and/or unenforceable. In this study, we showed that the home range of *L. harak* population of Emua and Paonangisu villages' CFRs was influenced by reef habitats and geomorphology. Specifically home ranges of sub-populations overlap along contiguous fringing reef while the habitat break between the northern and southern study sub-areas likely represented a natural barrier to *L. harak* movements. This barrier prevented connectivity between the northern sub-area and Takara village's CFR. Habitat breaks have been shown to limit reef fish movements (e.g. Meyer et al. 2010, Marshell et al. 2011) and should be considered when setting CFR networks in reef areas (Chateau and Wantiez 2008).

Although this study was limited to a single target species, our results provide three main arguments for establishing CFR networks in Vanuatu and other Pacific island countries. First, adult fish mobility across reserve and village boundaries allows for connecting neighbor CFRs that overlap with fish home range, hence increasing fish protection compared to individual CFRs. Second, the typically-small contiguous community tenures at island scale could decrease spacing between neighbor CFRs if the latter are widespread among coastal communities. A sufficiently large contingent of fish populations that live within a home range may consequently be capable of moving safely from a reserve to another, therefore increasing overall protection. For instance, the fidelity and spawning sites of *L. harak* may be protected by two CFRs located in Emua and Paonangisu villages, therefore reducing the probability of capturing those fish that exhibit long outward movements from Emua's CFR. Third, fish plasticity towards reef habitats and fidelity site locations may increase the choices which communities have regarding the designation of suitable areas to be protected from fishing whilst also taking into account local sociopolitical and socioeconomic factors.

The effectiveness of networks of small reserves that would be strategically located in areas where resident fish spend most of their time or undergo critical phases (i.e., spawning sites) is the subject of a growing debate (Grüss et al. 2011). Our results indicate that reserves must also be situated to allow for movement of adult fish of the focal species among protected habitats. This acoustic study is one of the first evidence-based contributions to reserve network design in the context of community-based management of coral reef ecosystems and fisheries. Although it needs to be extended to other community-managed areas and other target reef fish species to embrace the diversity of fishery contexts, our results encourage between-community governance relationships to improve CFRs' location, size and spacing. Further research is required to investigate how such CFR networks can provide effective long-term protection for a wide range of coral reef fish while sustaining fishery benefits.

Acknowledgements

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Conclusion de la Partie 1

1) Ce cas d'étude a fait intervenir deux approches méthodologiques très différentes (i.e., enquêtes sur les savoirs locaux et marquage acoustique) entre 2010 et 2014. Certaines des questions posées au niveau local de gouvernance (chapitre 1) ont pu être traitées par un programme de recherche ciblé en écologie (chapitre 2). Celui-ci a proposé des résultats spatiaux et quantitatifs pratiques pour dimensionner et localiser les réserves marines communautaires temporaires, qui sont utilisées comme véritable outil de gestion des pêches récifales dans de nombreux pays insulaires du Pacifique. Cette étude démontre ainsi la capacité de la démarche de recherche-action à répondre à des questions à fois analytiques et pratiques sur la gouvernance des petites pêcheries, en mobilisant différents champs disciplinaires et des sources de données variées en fonction des enjeux.

2) Les effets observés des interventions extérieures sur la création institutionnelle ont alimenté notre analyse du processus d'intervention (dont la recherche-action fait elle-même partie) et des conditions selon lesquelles il peut impacter de manière ponctuelle ou durable les institutions en place. Des médiateurs de l'intervention et des contingences internes et externes ont été explicités. Les préférences des acteurs locaux en termes de règles de gestion et leurs perceptions des risques de surexploitation étaient hétérogènes au sein des villages étudiés, et constituaient des facteurs qui affectaient la nature et la durabilité des institutions à l'œuvre. En incorporant ces attentes sociales en partie contradictoires dans des plans de gestion locaux selon une logique écosystémique, les interventions du cas d'étude ont en effet augmenté le nombre et largement diversifié les institutions locales en place. Cependant elles se sont révélées incapables de faire émerger des institutions locales durables, à l'exception d'un nombre très restreint de règles dont l'acceptabilité sociale était élevée, comme les réserves marines temporaires. L'efficacité de ces dernières était cependant dépendante de considérations écologiques (liées à la mobilité des ressources) et sociales (liées à la tenure maritime). La complémentarité des résultats entre les chapitres 1 et 2 a ainsi permis de montrer comment les caractéristiques des pêcheries agissaient comme des contingences de la performance des institutions. Les principales faiblesses des interventions étudiées portaient sur la multiplicité des actions promues malgré les divergences des intérêts locaux, la dépendance financière et technique développée vis-à-vis de ces interventions en raison de la faiblesse des capacités locales développées, et le manque d'évaluation objective de leurs résultats biologiques et économiques.

Ces observations soulignent ainsi l'importance de considérer d'une part les médiateurs, les contingences, et leurs effets sur les résultats finaux lors de la conduite d'interventions sur les petites pêcheries, conformément à notre modèle causal théorique, et d'autre part l'approche méthodologique développée par ces interventions (e.g., visant ou non les objectifs de la démarche de recherche-action telle que présentée en introduction).

3) Les médiateurs et contingences mis en évidence ont permis d'expliciter des articulations verticales et horizontales pertinentes à développer, qui variaient en fonction des pêcheries, afin d'améliorer la performance des institutions les plus prometteuses en termes d'impacts sur l'exploitation. Sur la base de ces résultats, nous avons recommandé des stratégies qui ont été présentées et discutées avec les acteurs locaux et gouvernementaux, y compris à l'aide d'un support documentaire (https://www.ird.fr/la-mediatheque/videos-en-ligne-canal-ird/aires-marines-taboues-du-vanuatu), en raison de l'importance des échanges oraux dans la culture mélanésienne (White 2007). Ces échanges visaient à inscrire les résultats dans une réflexion élargie sur l'appui des interventions publiques à la gouvernance multi-échelle au Vanuatu.

PARTIE 2. Gouvernance multi-échelle des petites pêcheries : dynamique et évaluation institutionnelle

Introduction de la Partie 2

La partie 1 a montré la pertinence de la recherche-action pour i) souligner le rôle de certains médiateurs et contingences à prendre en compte lors d'interventions sur la gestion des pêcheries récifales, et ii) comprendre l'intérêt potentiel d'une gouvernance multi-échelle qui soit adaptée au contexte des petites pêcheries, en particulier la mobilité des ressources et l'organisation socio-spatiale des pratiques de pêche. En continuité de ces apports, il s'est agit de concevoir des interventions, appuyées par notre recherche- action, qui soient capables d'opérer une évolution de la gestion communautaire des ressources récifales vers une coopération explicite avec les autorités publiques en charges des pêches dans le cadre des politiques des pêches (Pomeroy et Viswanathan 2003).

La partie 2 présente ainsi comment deux interventions ont été définies, mises en œuvre et évaluées entre 2008 et 2016 en ciblant l'ensemble des compartiments de notre modèle causal théorique. L'objectif pratique consistait à déterminer les conditions d'une exploitation durable des ressources, à expérimenter de nouvelles règles de gestion et de nouveaux modes de gouvernance jugés pertinents, et à analyser les facteurs favorables au processus de cogestion des petites pêcheries selon une approche empirique et dynamique.

Les interventions ont été réalisées dans des pêcheries d'holothuries en Nouvelle-Calédonie et au Vanuatu.

Si le choix de réduire la diversité des cas retenus a restreint *de facto* les perspectives de généralisation de nos résultats, il a permis d'une part de favoriser en pratique les interactions potentielles entre les cas d'étude, en raison de la similitude des enjeux et des solutions expérimentées, et d'autre part de diminuer le nombre de facteurs causaux potentiels explicatifs des trajectoires observées dans nos cas d'étude, et donc d'augmenter la robustesse de l'analyse du processus institutionnel.

Le choix s'est porté sur des ressources peu mobiles, ne rencontrant donc pas les difficultés propres aux ressources ayant une capacité de dispersion au stade adulte, abordées dans la Partie 1. Les holothuries sont des invertébrés benthiques sédentaires après de leur phase larvaire dispersive, ce qui constitue une condition favorable au développement de mesures spatialisées d'évaluation et de gestion des ressources (Perry et al. 1999 ; Castilla et Defeo 2001). De plus, le contexte local, national et global des pêcheries d'holothuries a créé une fenêtre d'opportunité pour étudier notre problématique. S'agissant de pêcheries d'exportation,

les circuits de commercialisation des holothuries étaient structurés par rapport à d'autres pêcheries récifales. La forte diminution des exportations d'holothuries dans la plupart des îles du Pacifique depuis une vingtaine d'années a par ailleurs incité les gouvernements et certaines communautés villageoises à prendre des mesures d'urgence sous la forme de moratoires et de fermetures temporaires locales, et plus globalement, à réviser leurs modes de gestion et à rechercher des solutions innovantes. Les holothuries sont en effet très recherchées à l'échelle mondiale depuis l'essor du marché en Chine dans les années 1990, et très vulnérables à la pêche pour des raisons biologiques et écologiques (Purcell et al. 2010). En l'absence d'une gouvernance efficace, l'exploitation de ces ressources présente une trajectoire typique et prédictible de développement rapide puis d'effondrement sur de courtes périodes, souvent de moins de 20 ans (Anderson et al. 2010). Les régulations conventionnelles (e.g., tailles minimales) rencontrent par ailleurs de sérieuses difficultés pour être effectivement appliquées. Ainsi, les pêcheries d'holothuries de chacun de nos cas d'étude étaient fermées au début de notre intervention pour cause de surpêche.

Chapitre 2.1. La bonne performance de la cogestion d'une pêcherie récifale à l'échelle locale

Léopold M., Cornuet N., Andréfouët Serge, Moenteapo Z., Duvauchelle C., Raubani J., Ham J., Dumas P. (2013). Comanaging small-scale sea cucumber fisheries in New Caledonia and Vanuatu using stock biomass estimates to set spatial catch quotas. Environmental Conservation 40, 367-379.

Ce chapitre présente le processus d'intervention dans une pêcherie monospécifique surexploitée d'holothuries en Nouvelle-Calédonie entre 2008 et 2011 (cas d'étude 2, Figure 5). Nous avons procédé à partir du cas restreint d'une unité sociale à petite échelle, localisée sur le territoire maritime de deux villages, totalisant une soixantaine de pêcheurs qui opéraient à partir de petites embarcations motorisées (Tableau 1).

La concertation s'est effectuée au sein d'une organisation informelle réunissant les pêcheurs des deux villages concernés, les autorités coutumières locales, et les autorités publiques provinciales. Un système informel de cogestion a été instauré en 2008. Celui-ci était basé sur la définition de totaux admissibles de captures (TACs) collectifs, d'un quota individuel et non transférable par période de pêche, de droits d'accès exclusifs (licence de pêche spéciale) attribués aux pêcheurs des deux villages sur la base de liens territoriaux ou de parenté, de suivis participatifs des captures et des ressources (basés sur des estimations directes), et d'un appui technique au service des pêches provincial (outils statistiques d'analyse orientés utilisateurs (http://bdmer.ird.nc/), permettant la diffusion rapide des résultats des évaluations des ressources).

Les questions posées étaient les suivantes :

1) Quels facteurs influencent le processus de coopération et de création institutionnelle, et sa performance ?

2) Quels sont les rôles des acteurs impliquées et les connaissances mobilisées dans ce contexte spécifique ?

3) Quelle a été la performance des institutions mises en place ?

A notre connaissance, ce chapitre présente la première expérimentation réussie du point de vue biologique et économique de la gestion d'une pêcherie récifale par TAC associant des communautés locales et l'administration publique chargée des pêches dans les pays insulaires du Pacifique.

Abstract

Most sea cucumber fisheries have collapsed worldwide due to rapid overexploitation and ineffective management. This study designed an innovative management strategy for small-scale, data-limited sea cucumber fisheries in Pacific Island countries. Firstly, a local quota-based co-management system was implemented in New Caledonia to manage a small-scale sandfish *Holothuria scabra* fishery. A habitat map derived from high-resolution satellite imagery was used to stratify data collection and assess the harvestable stock biomass. The latter has been monitored since 2008 and repeatedly used by the local fishers' organization to set adaptive total allowable catches and regulations of fishing effort. Results showed the excellent performance of this fishery between 2008 and 2012, both biologically (e.g. 167% increase in total stock biomass) and economically (e.g. 146% increase in annual returns from catches). Secondly, the assessment of the reference biomass was generalized to multispecies sea cucumber fisheries in Vanuatu in 2011, one year before the proposed lifting of a 5-year national moratorium. Building upon these practical case studies in New Caledonia and Vanuatu, we developed an operational framework to inform sea cucumber fisheries policy in these two countries. The proposed management strategy has the potential to turn the tide of resource depletion in artisanal sea cucumber fisheries in data-limited contexts.

Résumé

De nombreuses pêcheries d'holothuries ont décliné de manière importante à l'échelle mondiale en raison d'une surexploitation rapide et d'une gestion inefficace. Cette étude a élaboré une stratégie de gestion innovante des petites pêcheries d'holothuries dans les pays insulaires du Pacifique, où les données sont limitées. Un système de cogestion par quota a d'abord était mis en œuvre en Nouvelle-Calédonie pour gérer une petite pêcherie d'holothurie grise *Holothuria scabra*. Une cartographie des habitats réalisée à partir d'imagerie satellitaire à haute résolution a été utilisée pour stratifier l'échantillonnage et estimer la biomasse du stock exploitable. Celle-ci a été définie comme biomasse de référence et suivie de 2008 à 2011. Elle a été utilisée de manière répétée par l'organisation locale des pêcheurs et les agents du service des pêches pour établir des totaux admissibles de captures et des régulations de l'effort de pêche de manière adaptative. Les résultats ont montré l'excellente performance de la pêcherie de 2008 à 2012, sur le plan biologique (augmentation de 167 % de la biomasse totale du stock) et économique (augmentation de 146 % des revenus annuels issus des captures). Dans un second temps, l'évaluation de la biomasse de référence a été généralisée à des pêcheries multi-spécifiques d'holothuries au Vanuatu en 2011, avant la levée proposée d'un moratoire national de cinq ans. A partir de ces cas d'études pratiques en Nouvelle-Calédonie et au Vanuatu, cet article définit un cadre de travail à l'attention des politiques publiques sur les pêcheries d'holothuries dans ces deux pays, et discute la généralisation de la stratégie de gestion proposée.

Key-words

Co-management procedure; fishers' organization; habitat mapping; New Caledonia; precautionary approach; sea cucumber; small-scale fisheries; stock biomass assessment; Vanuatu.

1. Introduction

Many sea cucumber fisheries have collapsed worldwide in the last twenty years due to overexploitation and ineffective management arrangements (Purcell et al. 2011). The typical boom and bust trajectory of these fisheries suggests that lack of effective management puts sea cucumber resources at high risk in the short term, as reported for other similar high-value invertebrate resources (Castilla and Defeo 2001; Anderson et al. 2011). Sea cucumbers are indeed depensatory mortality species, which means that reproductive success and recovery are far less effective when population density decreases, ultimately with a risk of local extinction. To sustain these fisheries in the long term, the fundamental goal is then to implement precautionary management that maintains sea cucumber resources above their biological recovery threshold, whilst also supporting sustainable harvesting activity (Shepherd et al. 2004).

Conceptual indicator-based approaches to fisheries have expanded considerably and provided theoretical guidelines for the application of the precautionary principle to fisheries management (Garcia 1994). Specifically, uncertainty in resource assessments needs to be taken into account to establish regulatory measures in the case of vulnerable species, such as sea cucumbers. Monitoring biological, socio-economic and environmental indicators is recommended to evaluate the effectiveness of invertebrate fisheries management on an adaptive basis, given the natural variability and the inherent uncertainty of survey data (Caddy 2004). The temporal variation of indicators can be analyzed across a time series and compared to critical threshold values of these indicators, named reference points (Caddy and Mahon 1995). However, approaches based on indicators and reference points have been considered expensive and difficult to implement in data-limited contexts, such as those found for small-scale fisheries in poorly developed countries (Seijo and Caddy 2000). For instance, although the maximum sustainable yield (MSY) of a fishery is widely used in TAC-based fisheries management, this target reference point cannot be considered in most small-scale invertebrate fisheries due to scientific knowledge gaps in biological and fishing data (Perry et al. 1999; Purcell 2010a).

Recent reviews of sea cucumber fisheries management have highlighted sustainable practices to meet conservation, social and economic objectives in the long term (e.g. Friedman et al. 2008; Anderson et al. 2011; FAO 2010; Friedman et al. 2011; Purcell et al. 2010). However these authors acknowledge that their recommendations remain largely hypothetical because the effects of those recommendations remain poorly documented. Information on the ability of management options to achieve predefined management

objectives is needed for selecting the most appropriate regulatory measures and for ruling out those unlikely to succeed. For instance, the heterogeneous distribution of sea cucumber populations calls for spatially-explicit regulatory measures. This requirement is typical for sedentary and low-mobility species whose growth, mortality, recruitment and aggregation vary with habitat distributions (Caddy 1989). Defining regulatory measures on a scale too large, given the ecological traits of the target species, may lead to local overexploitation and local extirpation. For example, setting up a total allowable catch (TAC) or quota of sea cucumbers at a national level may not prevent spatial serial depletion and fishery collapse, even if the overall TAC has not been reached. Identifying the factors and conditions that lead to successful sea cucumber fisheries management at a local level seems to be a priority before implementing large-scale strategy and different management levels (Cash and Moser 2000).

In Oceania, the effectiveness of coastal fishing management largely relies on the support and compliance of fishers and local communities. This is due to the fact that on the one hand, territorial fishing rights and customary ownership of inshore marine resources are enforced through customary marine tenure, and on the other hand, the government has a limited capacity to collect and process biological and fishing data so as to enforce national fishing regulations. These national fishing regulations usually include gear restrictions to prohibit the use of destructive fishing practices and the setting of minimum harvest sizes to reduce the mortality of immature and sub-adult individuals. As part of this study, sea cucumber fisheries management was examined in Vanuatu and New Caledonia. In Vanuatu, both community-based and governmental management did not prevent the sea cucumber fisheries collapse, although a national quota of 26 t was established in 2005, leading to a 5-year national moratorium in 2008. The Fisheries Department of Vanuatu may lift the fishing ban in 2013 on the sites where resources have recovered sufficiently. In New Caledonia, sea cucumber exports have declined from 94 to 34 $t.yr^{-1}$ for the last five years, and local overexploitation of the highest value species has been observed by provincial Fisheries Departments. This has encouraged the latter to seek more effective management alternatives.

This study describes a multi-scale strategy applied to New Caledonia and Vanuatu (South Pacific) for the operational management of artisanal sea cucumber fisheries in data-limited contexts. Specifically, a local adaptive co-management system was put into effect in 2008 in New Caledonia to manage a previously depleted small-scale single-species sea cucumber fishery. The initial harvestable stock biomass was assessed and has been regularly monitored since then. This has then been used as a reference biomass to implement local TAC and regulations of fishing effort. Biological and economic performance and the key factors for success of the co-management system have also been evaluated. The methodology for estimating the reference biomass has been generalized to multispecies sea cucumber fisheries in Vanuatu. Lessons from these case studies provided fresh insights into the successful spatial up-scaling (i.e. from one site to multiple sites) of the local co-management system in these two countries. This has then been used to develop an operational framework to inform sea cucumber fisheries policy.

2. Methods

2.1. Defining the appropriate reference point of a single-species sea cucumber fishery

The study focused on the main fishery for sandfish *Holothuria scabra* in New Caledonia. This was a single-species fishery located in the Northern Province on a 26 km² shallow coastal reef flat covered by seagrass beds (Fig. 1 A). The fishery has been traditionally operated and ruled since the 1990s by the fishers from the Melanesian village of Boyen (200 inhabitants) and, occasionally, by two neighbouring villages. The only restrictive provincial fishing regulations were the ban on night fishing and the minimum harvest size of 20 cm. Fishing gear restrictions (i.e. the use of scuba equipment and drag nets) were not applicable in the shallow waters of the study area. In the early 2000s, fishers reported a decline in commercial sized sandfish, suggesting that the resources had been depleted. Thus, landowners and the local fishers' organization temporarily closed the fishery in 2007. They then requested assistance from the provincial Fisheries Department to define the catch level according to the biological capacity of the fishing ground.

To define an appropriate TAC, we investigated the use of a biological reference point for characterizing the stock status. The harvestable stock size (in tonnes of live-weight animals) was used here as the local reference point (hereafter reference biomass or RB) to address the risk of recruitment overfishing. According to Conand (1993), wild sandfish reach maturity at around 16 cm in New Caledonia, which corresponds to around two years of age depending on growth rates (Hamel et al. 2001; Purcell and Kirby 2006). The RB was linked to the abundance and size of sea cucumbers, which were directly affected by fishing and therefore expected to decrease when the exploitation rate increased. The expected sensitivity to short-term effects of fishing allowed for near real-time tracking of the resource status. In addition, abundance and size of sea cucumbers were two indicators easy to interpret and measure by fishers and Fisheries Department officers. High sensitivity, significance and measurability of the RB were desirable characteristics for the planned management scheme (Rochet and Trenkel 2003).

Four additional biological indicators were suggested by scientists and assessed in the study site: total stock abundance (in number of individuals), total stock biomass (in t), mean density of sandfish (in individual.km^{-2}), and mean individual weight of sandfish (in g). The recommended and observed exploitation rates of the sandfish fishery were estimated by the ratio of the TAC and observed catches to the total stock size, respectively.

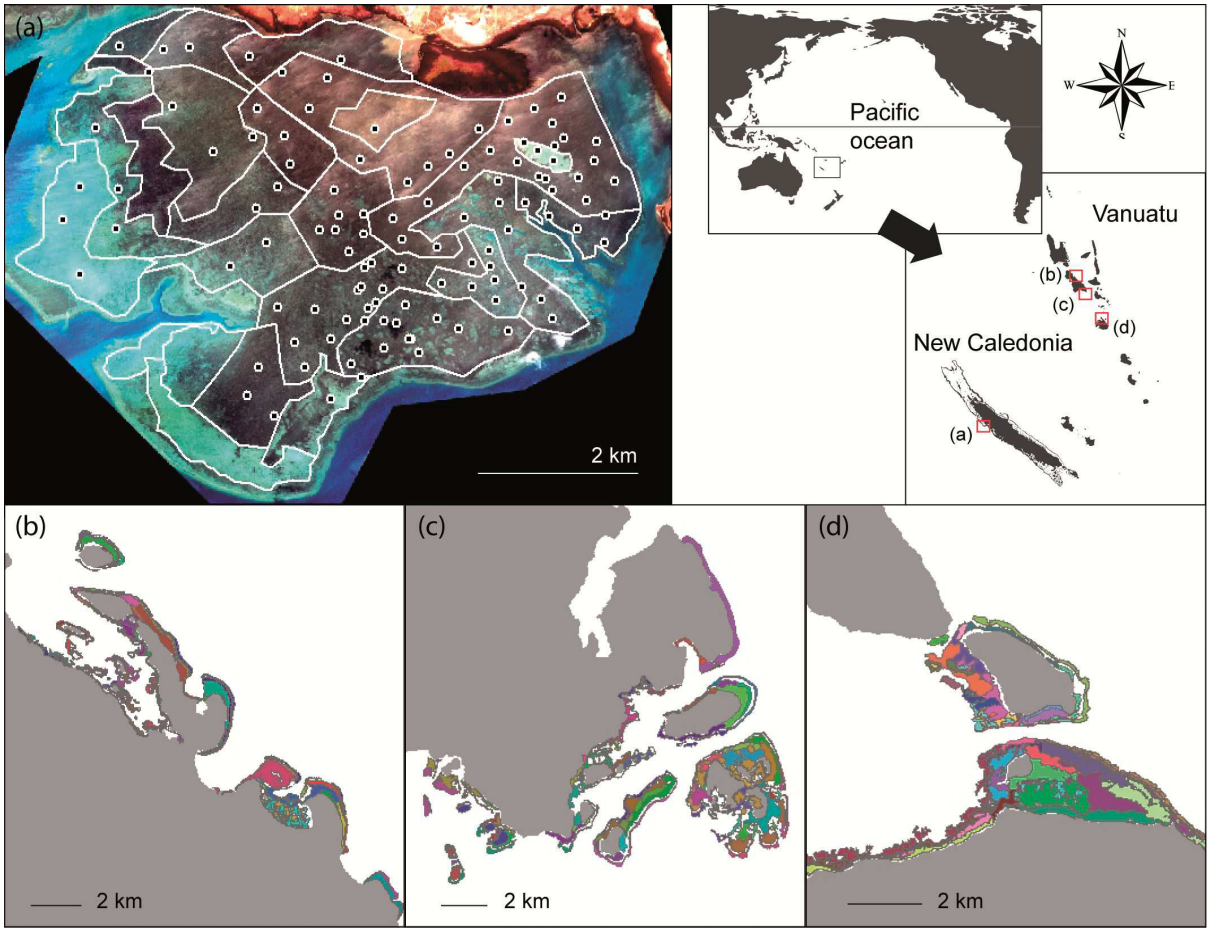

Figure 1. Sites defined for field surveys in New Caledonia (A) and Vanuatu (B, C, D). A: Quickbird satellite image of the sandfish *Holothuria scabra* fishery. The 25 polygons were defined by photo-interpretation and correspond to different habitat zones according to seagrass density, sediment patches and reef edges. The 123 permanent transects for sandfish census (white circles) were randomly located within each habitat proportionally to the habitat surface area. B (Malikolo Island), C (Maskelynes Islands), D (Efate Island): coloured zones were defined by photo-interpretation of Worldview II satellite images and correspond to different habitat zones according to seagrass density, sediment patches, reef edges, exposure, depth, and geomorphological entities.

2.2. Estimating the reference biomass of the fishery

The RB was estimated eight times between June 2008 and April 2012 through field census conducted in the fishing area, using a rapid and inexpensive survey method. The observation units were 100 m-long and 2 m-wide belt transects (i.e. 200 m² per transect). All individuals found within the transects were counted and measured to the nearest 5 mm (length (L) and width (W)). Individual weight (P) was derived from Equation 1 (Purcell et al. 2009).

$$P = 1.186 * \left(\pi * \frac{L * W}{4} \right)^{1.259} \quad \text{Equation 1}$$

Depending on the stage of the tides, counts were conducted either by walking on the reef flat or snorkelling in areas down to 2 m depth. The teams consisted of two observers comprised of fishers and Fisheries Department officers. Marine habitats were used to spatially stratify data collection in the fishery (e.g. Skewes et al. 2002; Aumeeruddy et al. 2005). A map of marine habitats was created using a multispectral 2.4 m-spatial resolution Quickbird satellite image (Fig. 1 A). The image was processed as recommended in Andréfouët (2008). Twenty-five polygons were photo-interpreted using differences in colour and texture due to different seagrass densities, sediment patches and reef edges visible on the image. We thus assumed that the 25 polygons reflected different habitat zones, although they were all variations of seagrass habitats. The map was imported into a geographical information system to calculate habitat surface areas. This simple mapping process was used to compute stock estimates using habitat surface areas (in km^2) and sea cucumber density (in individual.km^{-2}) (Hamel and Andréfouët 2010).

The area considered for most surveys corresponded to the highly productive and heavily targeted 12-15 km^2 area of the reef flat. However, the entire fishing area (26 km^2) was surveyed during the first and seventh surveys (June 2008 and October 2011, respectively). The sampling effort resulted from a compromise between data quality issues and survey duration. Two to 20 transects were randomly sampled per habitat zone proportionally to the surface of the latter, resulting in a total of 40 to 112 fixed transects according to the extent of the survey area (Fig. 1 A). The mean sampling rate has increased across the study period from 2.5 transects.km^{-2} in 2008 to 4.2 transect.km^{-2} since 2009.

Count data was integrated into a database that performed statistical estimations using user-defined algorithms. The mean density (in individual.km^{-2}) and biomass (in kg.km^{-2}) of all and legal sized sandfish, with associated standard error, were firstly calculated within each habitat zone. Secondly, they were multiplied by the habitat surface area to estimate the abundance and biomass of the entire and harvestable stocks within each habitat zone, respectively. The latter were summed up across habitat zones to give the estimated total and harvestable stock abundance and biomass, respectively. The mean density of sandfish was estimated by dividing the total stock abundance by the surface of the survey area. The mean individual weight of sandfish was estimated within each habitat zone and then extrapolated to the entire survey area. The associated 95% confidence intervals of all estimates were calculated using common statistical inference procedures. The RB corresponded to the lower limit of the 95% confidence interval of the estimated harvestable stock biomass at the time of survey.

2.3. Generalizing the reference biomass for the management of multispecies sea cucumber fisheries

The RB was estimated for 15 commercial sea cucumber species at three sites in Vanuatu, located on the islands of Malikolo, Maskelynes, and Efate (Fig. 1 B, C, D, Table 1). Communities in these sites were used to temporarily closing their marine territory to sea

cucumber fishing due to the heavy depletion of the resources before the national moratorium came into effect. The habitat maps of the sites exhibited a much greater diversity than the New Caledonian study site, with 37 to 72 habitat zones per site (Fig. 1 B, C, D). Suitable habitats for each species were determined based on literature (Conand 1998; Tuya et al. 2006; Bellchambers et al. 2011). Sampling efforts reached between 171 and 286 transects per site, i.e. from 10 to 15 transect.km^{-2}. Data collection was conducted in 2011 using the same methods as previously described for the survey in New Caledonia. Nevertheless, the use of scuba equipment, although not essential, sometimes facilitated counts of species down a depth of 10 m, which was the average depth limit for sea cucumber fisheries in Vanuatu. The length-weight relationships for each species were taken from Conand (1989).

Table 1. Sea cucumber reference biomass (in t) in the survey site (A) in New Caledonia) and the three survey sites (B, C, D) in Vanuatu in 2012 and 2011, respectively. Live minimum harvest sizes are shown for both countries. The width of the 95 % confidence interval of total stock biomass estimates is in parenthesis. * Estimated biomass lower than a ton. ** Lollyfish *Holothuria atra* minimum harvest size may decrease from 30 cm to 20 cm in 2013. N. C.: New Caledonia.

	Legal size (cm)		Total stock (t)				Reference biomass (t)						
Commercial species	N. C.	Vanuatu	N. C.	Vanuatu			N. C.	Vanuatu					
			site A	site B	site C	site D	site A	site B	site C	site D			
Actinopyga mauritiana	25	20		*	*	*		*	*	*			*
Actinopyga milliaris	25	-		*	*	*		*	*	*			*
Bohadschia argus	-	20		11.5 (7.1)	31.8 (14.4)	6.4 (3.5)		4.5	15.6	2.9			15.6
Bohadschia similis	-	-		*	*	*		*	*	*		0.490566038	*
Bohadschia vitiensis	-	20		14.3 (9.1)	40.8 (31)	*		5.2	8.1	*			8.1
Holothuria atra	-	20**		70.7 (26.3)	247.6 (70.2)	15.5 (5.2)		*	61.4	*			61.4
Holothuria edulis	-	25		1 (0.6)	*	*		*	*	*		0.247980614	*
Holothuria fuscogilva	35	35		*	*	*		*	*	*			*
Holothuria fuscopunctata	-	-		*	*	*		*	*	*			*
Holothuria scabra	20	22	306.5 (49)	*	*	*	84.7	*	*	*			*
Holothuria whitmaei	30	22		8.4 (14.2)	10.9 (9)	*		*	1.7	*			1.7
Stichopus chloronotus	-	20		10.4 (8)	9.4 (6.4)	9 (4.4)		2.5	1.0	2.4		0.106382979	1.0
Stichopus herrmanni	35	25		7.8 (6.5)	42.9 (30.4)	*		1.3	11.7	*		0.272727273	11.7
Thelenota ananas	45	32		5.5 (5.5)	11.1 (7.2)	10.1 (6.7)		*	3.8	2.5			3.8
Thelenota anax	-	-		*	*	*		*	*	*			*

3. Results

3.1. Biological change in the New Caledonia sandfish fishery

The RB and total stock of sandfish regularly increased across the study period, emphasizing the strong positive biological effects of the co-management regime across all of the size classes. The RB raised from 13 to 85 t (+566%), i.e. from 28,000 to 224,000 individuals (Fig. 2 A). Similarly, the total biomass markedly increased from 115 ± 30 t to 307 ± 49 t (+167%), i.e. from 471,000 ± 126,000 to 1,138,000 ± 167,000 individuals (+142%). While the RB represented 11% of the total stock in 2008, it reached 28% in 2012. The increase in RB was spatially restricted to the reef flat area perceived as very productive by local fishers.

Other biological indicators showed less marked and irregular fluctuations compared to the RB across the study period (Fig. 2 B). The change in mean individual weight of sandfish ranged from -6% to +24% during the eight monitoring surveys compared to its initial level, with an overall increase of 11% between 2008 and 2012. The mean sandfish density increased by 312% from 18,300 to 75,400 individual.km^{-2} between 2008 and 2012, even though a sharp decline occurred in 2011.

3.2. Integrating the RB in a co-management cycle

We observed that the occurrence of overfishing has prompted, at a local level, a desire to improve resource stewardship and achieve greater accountability in the management of the sandfish fishery. Specifically, the fishers' organization has developed an iterative and adaptive management procedure to set fishing restrictions based on biological monitoring data. The RB was implemented following an innovative co-management cycle structured in four steps (Fig. 3).

Firstly, the RB was estimated following the methods described above.

Secondly, the RB was discussed between the Fisheries Department officers and the fishers' organization to set a collective TAC (live weight) equal to the RB. As fishers eviscerated sea cucumbers at sea and marketed the salted product, the initial TAC was converted into a TAC of gutted and salted products. The rate was set at 0.85 for the first six surveys due to measurement errors with the local conversion rate, and then reduced to 0.5 for the last two surveys based on the recommendations of Skewes et al. (2004).

Thirdly, the fishery was re-opened, along with the introduction of regulations of fishing effort. Specifically, a limitation on fishing periods and an allocation of fishing rights were established by the fishers' organization. The fishery was not opened permanently, but rather, for short periods of time, to control the level of catch and prevent illegal fishing. Open periods lasted from one to three days each and were repeated two to seven times, depending on the size of the TAC and the fishing yields. In particular, these open periods took place at the end and at the beginning of the year to cover expenses related to Christmas holidays and school fees. Local fishing rights were regulated through both individual quotas per open

period, to prevent a "race" for sea cucumbers and individual appropriation of the TAC, along with annual fishing licenses per vessel (i.e. one to five fishers). The total number of licenses has been limited to 27 since 2009. Sales to middlemen took place immediately after each open period. The cumulative catch sold since the first opening day of the co-management cycle was monitored by a Fisheries Department officer and a leader of the fishers' organization to check compliance with the TAC.

Lastly, the fishery was closed again as soon as the TAC was reached, until the fishers' organization planned a new survey to estimate the RB, marking the beginning of a new co-management cycle.

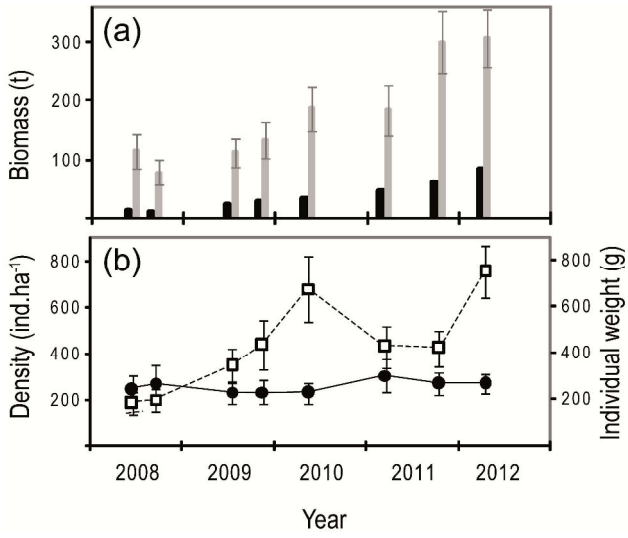

Figure 2. Evolution of biological indicators across the eight co-management cycles (2008-2012) in the surveyed sandfish *Holothuria scabra* fishery in New Caledonia. A: reference biomass (black bars) and total stock biomass (grey bars). B: mean density (white squares) and mean individual weight (black circles). Vertical bars represent 95 % confidence intervals.

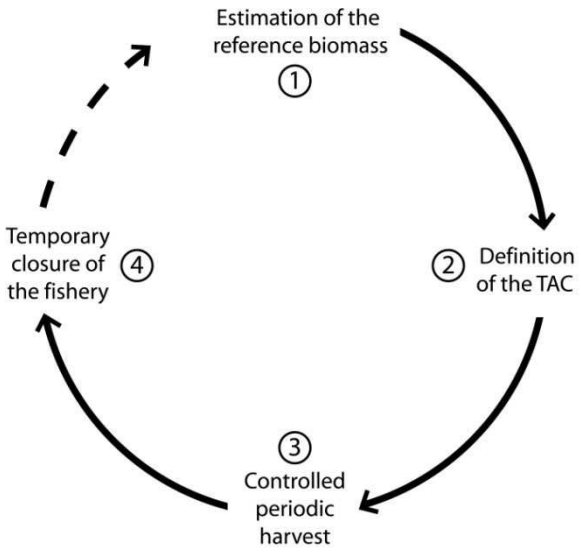

Figure 3. Four-step co-management procedure implemented in the surveyed sandfish *Holothuria scabra* fishery in New Caledonia between 2008 and 2012: 1) statistical estimation of the harvestable stock biomass and the reference biomass using habitat-based stratified sampling and participative biological surveys; 2) definition of the total allowable catch (TAC) based on the reference biomass; 3) controlled periodic harvest of sea cucumbers including regulations of fishing effort and the monitoring of sales; 4) temporary closure of the fishery when the TAC has been reached.

This co-management cycle was repeated eight times between 2008 and 2012, and each time the TAC was updated based on the RB. The cycle duration ranged from three to ten months. Catches recorded at each cycle increased from 8 to 35 t (+338%) proportionally to the RB (Pearson coefficient=0.746, p=0.03). It peaked at 42 t during the sixth co-management cycle (Fig. 4 A). Although the RB regularly increased, a 40% drop in catch was observed in the second half of 2011 corresponding to the reduction of the conversion rate of live weight to gutted and salted weight from 0.85 to 0.5. This resulted in a 50% decrease in the recommended exploitation rate, which varied from 6% to 21% over the period (13% on average) (Fig. 4 B). However, the observed exploitation rate ranged from 8% to 27%, indicating that the catch generally exceeded the TAC (up to 69% in 2011).

The mean number of fishers and the income gained by each fisher increased from 30 to 61 (+103%) and from US$1,900 to US$3,700 (+95%) between the first and last co-management cycles, respectively (Fig. 4 C). The cumulated catch value generated at each cycle grew from US$57,000 to US$225,000 (+295%) between 2008 and 2012 (i.e. US$2,200 km^{-2} to US$14,900 km^{-2}). Annual catches raised from 20 t in 2008 to 50 t in 2012 (+150%), generating US$138,000 and US$341,000, respectively (+146%). These results showed the excellent performance of the fishery, both biologically (increased resource biomass) and economically (increased incomes).

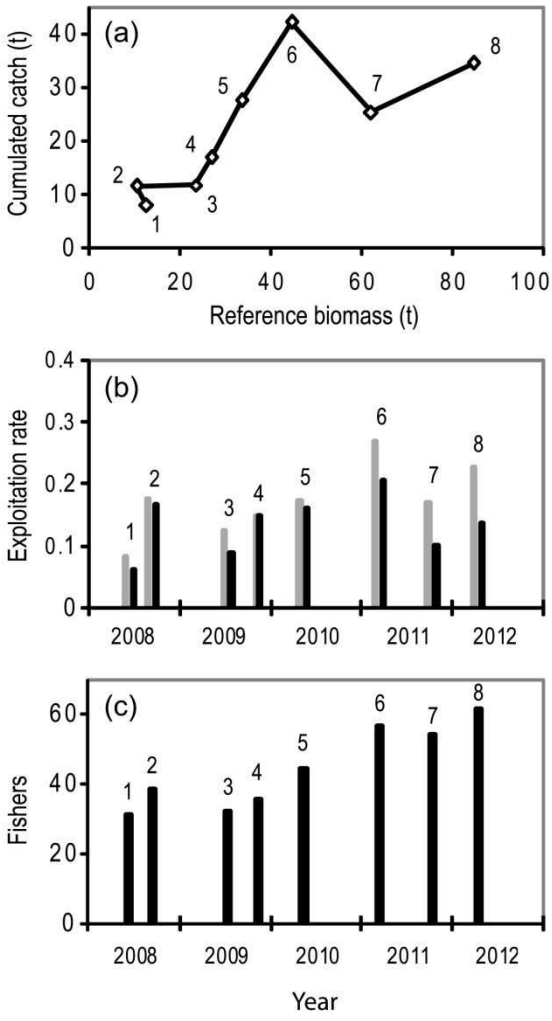

Figure 4. Evolution of fishing activities across the eight co-management cycles (#1 to 8) in the surveyed sandfish *Holothuria scabra* fishery in New Caledonia between 2008 and 2012. A: cumulated catches relative to the reference biomass. B: recommended (black bars) and observed (grey bars) exploitation rates. C: number of fishers.

3.3. Estimates of the RB in Vanuatu multispecies fisheries

In Vanuatu, the RB of sea cucumber stocks in the three study sites was very low for almost all surveyed species. The RB reached less than a ton for 67% to 86% of the species amongst sites (Table 1). This finding suggested that the sea cucumber resources had recovered little, after four years of moratorium. In particular, the RB for sandfish was lower than a ton. This was well below the level observed in New Caledonia before the launching of the co-management process (i.e. 13 t, Fig. 2 A).

Although most sea cucumber stocks appeared depleted across the archipelago, biomass estimates showed marked spatial difference (Table 1). Specifically, total stock and reference biomass of four species were significantly higher in the site D: Lollyfish *Holothuria atra* (248 ± 70 t and 61 t, respectively), Leopardfish *Bohadschia argus* (32 ± 14 t and 16 t), Curryfish *Stichopus herrmanni* (43 ± 31 t and 12 t), and Brown sandfish *Bohadschia vitiensis* (41 ± 31 t and 8 t). The RB of these species represented from 11% to 49 % of the total stock biomass.

The moratorium on sea cucumber harvesting in Vanuatu at the time of the survey did not allow for the implementation of the RB in the study sites in this country.

4. Discussion

4.1. Addressing uncertainty issues in stock estimates

Management approaches based on reference points typically incorporate pre-defined biological and fishing parameters derived from assumptions and approximations. These parameters are in fact rarely optimized to the local fishery conditions due to knowledge gaps. They may also be affected by subjectivity decisions, which contribute to create uncertain reference points and complicate their interpretation (Trenkel and Rochet 2003; Patterson et al. 2001). For example, a minimum density of sea cucumbers has commonly been recommended as a biological threshold for fisheries (e.g. Purcell 2010a; Friedman et al. 2011), although quantitative data on the related density-dependent processes (e.g. recruitment, mortality) is lacking for most exploited species. Similarly, although a 5 % fishing mortality may be conservatively prescribed to determine TAC in certain cases (e.g. Purcell 2010a), the sustainable exploitation rate of the sandfish fishery in New Caledonia seems to exceed 15 %. Here, both the minimum density and optimal fishing mortality could not be precisely defined given current knowledge on sandfish ecology.

To address these uncertainties, our methodology uses 1) robust statistical assumptions based upon stratified random sampling to quantify the accuracy of stock estimates, and 2) conservative RB to limit the risk of overestimating the TAC. On the one hand, uncertainties in data collection occur in surveys especially due to highly variable habitat-specific and/or stage-specific detectability of most target species (e.g. Shiell and Knott 2008; Purcell 2010b).

Although these measurement errors are not quantifiable, they are conservative and the harvestable stock biomass is therefore probably underestimated. On the other hand, RB is defined conservatively using the lower bound of the 95 % confidence interval of the harvestable biomass.

Missed opportunities for higher catches are intrinsic to precautionary approaches and may not be well accepted by fishers. However, this study shows that this cost may be acceptable in sea cucumber fisheries ruled by territorial fishing rights (as in our survey sites), because sea cucumbers are sedentary resources and traditional rights held by fishers are valid on the long term (Scott 1989).

4.2. Reducing the uncertainty of the implementation of the RB

In this study, we have converted the theoretical approach of fisheries monitoring using indicators of pressure, state, impact and response advocated by Caddy (2004) to a simplified state-response cycle. The RB characterizes resource status and provides immediate and measurable change in exploitation through the TAC.

Our observations highlight that this "short-cut" approach has greatly facilitated the use of the RB in the local decision-making process in New Caledonia. This is in contrast with other indicators such as mean density and individual weight, for instance. The two latter indicators have not followed the same temporal dynamics as the RB in the sandfish fishery. This difference may come from the confounding effects of fishing and environment on sea cucumber resources due to the high spatial and temporal variability of Holothurian populations (Clark et al. 2009). Additionally, a change in mean density or individual weight of sea cucumbers would not directly and accurately determine a percentage increase or decrease in catches. Further uncertainties in setting the TAC may then cause discrepancies between stakeholders' perceptions about local regulatory measures, which would certainly affect the adaptive capacity and precautionary orientation of co-management (Charles 1998).

High economic returns and shared governance of the fishery have also created strong incentives to implement the RB and demonstrated the success of this co-management system in New Caledonia. On the one hand, the rapid recovery of sandfish resources and the increase in catches have urged co-managers to monitor the RB and enforce associated regulatory measures. Conservative levels of RB and fishing mortality have very likely contributed to prevent overexploitation of the sandfish fishery, despite the fact that catches often exceeded the TAC. On the other hand, the adaptive nature of the regulatory measures has also improved co-managers' involvement and commitment compared to other regulations, such as harvest size limits, for instance. Although harvest size limits in theory allow the same sandfish catch as the TAC, they operate as non spatial and intangible rules that do not involve fishers' decisions, resulting in low compliance in the absence of permanent outside controls and poor effectiveness in co-management systems (Gutiérrez et al. 2011).

4.3. Incorporating the reference biomass into spatial fisheries policy

The RB is currently the knowledge base of the local co-management system in New Caledonia, as agreed by all stakeholders. Although it is uncertain whether this successful case study may be generalized on a larger scale, the spatial up-scaling of the co-management system as part of an artisanal sea cucumber fisheries policy appears to hold promise for sustaining resources. Our results suggest that multispecies sea cucumber fisheries management at a large spatial scale should take into account spatially-explicit regulatory measures set for each commercial species separately. This strategy is currently planned at a national and provincial level by Vanuatu and New Caledonia Fisheries Department, respectively. A spatial management framework is currently under development to fine-tune fishing regulations to the ecology of the resources and the activities of the fishers (Orensanz et al. 2005) (Table 2).

Table 2. Methodological guidelines to implement a spatial co-management framework for small-scale sea cucumber fisheries. Biological, technical, financial and social factors should be considered by Fisheries Departments to fine-tune fishing regulations to the ecology of the resources and the activities of the fishers.

	Main objectives	**Operational tasks of the Fisheries Department**
Biological factors	Estimating stock reference biomass per species in each fishery	(a) Identify priority sea cucumber fisheries (b) Estimate reference biomass before opening fishing (c) Define spatially-explicit total allowable catch (TAC) (d) Real-time catch monitoring to prevent overexploitation
Technical factors	Strengthening Fisheries Department capacities to reduce external assistance	(a) Collect biological data using simple survey techniques (b) Map marine habitats using simple remote sensing techniques (c) Use habitat-based stratified sampling and high sampling effort to estimate reference biomass (d) Use simple database and freewares (e.g. QuantumGIS) (e) Process the biological data in real time using pre- and user-defined routines created in the database
Financial factors	Careful planning to reduce and cover management costs	(a) Set appropriate time duration of fishery co-management cycles (e.g. maximum of one per year) to limit the costs associated with reference biomass updates (b) Set appropriate/rotating open fishing periods at provincial or national scale to be able to monitor each fishery without time conflict (c) Define adequate fishing ground size to enhance cost-effectiveness of monitoring programs (monitoring costs *vs* returns from catches) (d) Ensure that all beneficiaries financially support management costs (e.g. through licence fees)
Social factors	Promoting participation to enhance local stewardship and compliance with fishing regulations in the long term	(a) Strengthen co-management by encouraging local fishers' organizations (b) Ensure that fishers' organizations are the local regulatory authorities and contribute to the decision-making process (e.g., participate in data collection, have access to survey results, set local fishing restrictions, enforce TAC) (c) Ensure that fishers' organizations are the main beneficiaries of management (d) Involve scientists when initiating the management procedure (e.g. to optimize the biological sampling efforts) (e) Ensure that buyers and processors respect spatial fishing bans and open fishing periods

The spatial generalization of RB-based co-management involves determining TAC-based regulations on appropriate spatial scale. For statistical and stock assessment purposes, habitat surface areas were needed and derived from the interpretation of high resolution satellite images. There is evidence that different habitat typologies and thus different maps yield different stock estimates (Andréfouët et al. 2005; Gilbert et al. 2006; Andréfouët et al. 2009; Hamel and Andréfouët 2010). Optimal habitat typology is achieved where marine habitats can be mapped with high accuracy through remote sensing images and resource density significantly differs amongst habitats. Such an optimal habitat map was generated in the New Caledonian case study. It did not change markedly the initial spatial segmentation and number of habitats (described in the Methods section), and it yielded stock estimates similar to those identified by the initial simplified map. The low added-value of the optimal map could be explained in that case by the low complexity of the survey area, made up mostly of seagrass beds of different densities and species assemblages. Conversely, habitat mapping optimization was necessary for other fisheries operating in highly diverse habitats, such as giant clams (Andréfouët et al. 2005; Gilbert et al. 2006). However, our validation performed here for seagrass dominated habitats proves that simple habitat mapping methods can provide reliable and accurate estimates of sea cucumber stocks. This is an important lesson for the spatial generalization of fisheries management for countries with low remote sensing expertise (Andréfouët 2008).

Our study showed that in contrast with an ideal small-scale fishery monitoring program (e.g. Clua et al. 2005), monitoring the RB does not require either a data intensive program or fishery-independent stock surveys. This allows for a significant reduction of the cost of data collection. In our case studies, the start-up and recurrent costs of the RB monitoring ranged from US\$46 km^{-2} to US\$86 km^{-2} and from US\$120 km^{-2} to US\$490 km^{-2}, respectively (Table 3). These costs vary according to the extent of the survey area and the transport costs for Fisheries Department officers. Recurrent costs represented 10.4% and 1.5% of the returns from sandfish catches in the New Caledonian study site in 2008 and 2012, respectively. Monitoring costs have been fully covered by public institutions (i.e. scientists and Fisheries Departments) and fishers. However, this option would not be affordable on a large scale or in the long term in countries with limited resources. Fisheries management costs should rather be internalized, proportional to expected financial returns from catches and supported by all beneficiaries (Hilborn *et al*. 2005).

Table 3. Start-up and recurrent costs of sea cucumber reference biomass monitoring in the survey sites in New Caledonia (A) and Vanuatu (B, C, D). Start-up costs include marine habitat mapping (i.e. high resolution satellite image purchase and processing) in fishing areas. Recurrent monitoring costs include field surveys for collection of sea cucumber data (i.e. transport costs, Fisheries Department officers' field allowances and other functioning costs), data analysis (i.e. data entry into a database, estimation of reference biomass and other biological indicators), and cooperation between Fisheries Department officers, fishers' organizations and local communities before and after field surveys (i.e. survey planning and setting of total allowable catch). Equipment depreciation costs are not included.

Sites		Fishing area (km^2)	Start-up costs (US$)			Recurrent costs per survey								Recurrent incomes from catch (US$ km^{-2})
						Data collection				Data analysis* (US$)	Shared decision process* (US$)	Total RB monitoring costs (US$ km^{-2})	Catch monitoring* costs (US$ km^{-2})	
			Satellite image	Habitat mapping*	Total (km^{-2})	Sample size (transects)	Survey duration (days)	Surveyers*	Field survey (US$)					
New Caledonia	site A	12-26	900	700	62	40-122	1-3	3-4	1,500-4,000	350	350	183-292	58-204	2,200-22,300
Vanuatu	site B	14	1100	200	93	199	5	3	6,400	500	300	514	-	-
	site C	25	1400	350	70	286	5	5	7,000	500	300	312	-	-
	site D	15	500	200	47	171	5	2	1,400	500	300	147	-	-

* Fisheries Department officers. Reference costs: US$350 day^{-1} (New Caledonia) and US$50 day^{-1} (Vanuatu)

The study also highlights the importance of local social factors in the implementation of the RB through co-management and the participation of different stakeholders in particular: fishers, landowners, Fisheries Department officers, buyers and scientists (Table 2). Notably, the enhanced responsibility and accountability of the fishers' organization in New Caledonia have promoted complex management arrangements that would not have been achieved if the Fisheries Department acted in isolation. The fishers' organization indeed improved the legitimacy and therefore the acceptability of long-term regulatory measures (Jentoft 1989). Our results suggest that the rationale for involving local fishers' organizations in sea cucumber fisheries co-management would be threefold.

Firstly, due to the lack of scientific data on the spatial dynamics of sea cucumber populations, the social and economic conditions often drive the spatial boundaries of fisheries and therefore define the area appropriate to RB monitoring (Sen and Nielsen 1996; Wilson et al. 2006).

Secondly, biological monitoring should be carried out together by fishers' organizations and Fisheries Department officers given the widely recognized advantages offered by participatory monitoring programs (e.g. Danielsen et al. 2005). As highlighted by Walters and Pearse (1996), we also observed that the precautionary approach encourages fishers to get involved in field surveys so as to improve the accuracy of RB, which is a recurrent weak point of TAC-based management.

Lastly, the monitoring of RB is largely contingent on the sustainability of regulatory measures and on a shared decision-making process. This means that the responsibility for fisheries management should be partly held by fishers' organizations operating at small spatial scale (e.g. Yamamoto 1995; Castilla and Defeo 2001). Fishers' organizations can indeed mobilize the local social capital more easily than Fisheries Departments. They facilitate the decision-making process, improve conflict management and have distributive effects based on collective and individual preferences (Willmann 1999). The Fisheries Department may retain responsibility for large scale planning, estimating RB and fixing TAC size. For example, the role of the fishers' organization in restricting fishing effort and allocating fishing rights in the sandfish fishery in New Caledonia was essential to support TAC-based management. It greatly facilitated catch monitoring and acted as an additional precaution against possible excessive catches (Stefansson and Rosenberg 2005). Allocating individual quotas while the number of fishers was increasing has also secured individual returns and therefore the involvement of fishers in a long-term co-management strategy (Scott 1999; Parma et al. 2006).

5. Conclusion

Our case studies showed that the harvestable stock biomass is a very effective reference point in small-scale sea cucumber fisheries when incorporated in a TAC-based co-management system. Results stressed that spatial collective quotas associated with territorial fishing rights are appropriate management tools in small-scale sea cucumber fisheries, both ecologically and economically, as widely observed in artisanal co-managed fisheries (Gutiérrez et al. 2011). The synergy between biological and economic performance of fisheries then improves the resilience of co-management at a local level. It also buffers the effects of market fluctuations and any change in local leadership.

The co-management system was generalized through fisheries policy as a tool for good fisheries governance at a provincial or national level. More globally, the study confirms that community-based management offers suitable conditions to the implementation of TAC and co-management arrangements in sea cucumber fisheries in Pacific Island countries, where resource status is a major concern (Aswani 2005). Although other authors have formulated slightly different management recommendations, this study proposes an innovative TAC-based management strategy to small-scale sea cucumber fisheries that has been successfully tested. Other commercial invertebrate fisheries that show characteristics similar to sea cucumber fisheries (e.g. topshell trochus *Trochus niloticus*) could also benefit from similar management guidelines.

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Chapitre 2.2. Une expérimentation adaptative multi-échelle d'interventions dans la gouvernance de pêcheries récifales

Marc Léopold, Olivier Thébaud, Anthony Charles (soumis). The dynamics of institutional innovation: crafting co-management in small-scale fisheries. Global Environmental Change.

Les effets positifs de l'intervention dans une pêcherie d'holothuries à l'échelle locale présentés au chapitre précédent pendant une durée de quatre ans, et le transfert méthodologique du suivi biologique à des ressources multi-spécifiques d'holothuries, nous ont conduits à explorer le caractère généralisable d'une telle intervention à différentes échelles temporelles et spatiales (locale et nationale).

Dans le cadre de politiques publiques des pêches, l'intervention a été poursuivie dans le cas d'étude 2 jusqu'en 2016, et une extension géographique a été réalisée au Vanuatu (cas d'étude 3, Figure 5). Dans ce pays, l'intervention a été suivie à l'échelle nationale et dans sept cas d'étude locaux, où le type d'exploitation des holothuries était comparable au cas de Nouvelle-Calédonie (Tableau 1). A notre connaissance, il s'agit de la première expérimentation à l'échelle nationale dans un pays insulaire du Pacifique de la cogestion d'une pêcherie récifale par mise en place de limites de captures.

Un cadre d'analyse et explicatif global de la performance institutionnelle a été défini à partir de la littérature et de notre modèle causal théorique pour réaliser une étude diachronique et comparative de ces neufs cas d'étude. L'objectif était de suivre l'évolution de la performance des institutions pendant l'intervention de recherche-action en fonction des contingences. La grille d'analyse comprenait onze variables qualitatives, représentant les résultats de l'intervention (comportement des acteurs, niveau relatif des captures des espèces à haute valeur commerciale, niveau et évolution de la biomasse des ressources des espèces à haute valeur commerciale), les instruments mis en œuvre (respect des institutions, accompagnement légal, apprentissage individuel, capacités d'action, et forme d'organisation), et les interactions sociales (homogénéité des stratégies des acteurs, apprentissage collectif). Le nombre de modalités de chaque variable (trois à quatre) a été défini en fonction de la précision raisonnable des informations disponibles (Young 2002), et en évitant les modalités très peu représentées dans les cas d'étude.

La performance institutionnelle globale de chaque cas d'étude a été évaluée par une combinaison des onze variables ci-dessus à une fréquence annuelle pendant la durée de l'intervention dans chaque cas. Les variables ont été évaluées *a posteriori*, dans le cadre de ce doctorat, à partir de plusieurs sources de données quantitatives et qualitatives collectées pendant la recherche-action : évaluations biologiques des ressources, suivi des captures, réunions multi-niveaux d'acteurs à vocation informative et décisionnelle, recueil

d'informations historiques sur les processus institutionnels. Cette documentation a permis une reconstruction précise des trajectoires temporelles des variables dans les cas d'étude.

L'analyse multicritère des neuf interventions de recherche-action (huit cas d'étude locaux, dont un en Nouvelle-Calédonie et sept eu Vanuatu, et un cas national au Vanuatu – cf. ci-dessus) a permis d'analyser la dynamique de la performance institutionnelle en réponse à l'intervention et aux contingences internes et externes. Les questions étaient les suivantes :

1) Comment la gouvernance des petites pêcheries a-t-elle évolué au cours de la recherche-action dans les différents cas d'étude ?

2) Quels ont été les facteurs déterminants de l'intervention et des contingences locales sur la performance des institutions ?

3) Quelles différences ont-été observées entre les facteurs entre les cas et à l'échelle locale et nationale ?

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.

Résumé

En tant que systèmes socio-écologiques complexes, les petites pêcheries nécessitent une approche de la gouvernance à fois collaborative et axée sur les problèmes concrets, cohérente avec une vision contextualisée des enjeux de durabilité. Nous avons examiné la dynamique de la performance de la cogestion dans les petites pêcheries dans différents contextes et échelles temporelles et spatiales à travers une démarche de recherche-action. Dans neuf cas d'étude localisés dans le Pacifique sud, de nouvelles institutions de cogestion ont été intentionnellement mises en œuvre de 2008 à 2016 à travers des interventions des politiques des pêches pour répondre à des problèmes de surexploitation des ressources d'holothuries. Afin d'évaluer quantitativement et empiriquement le changement de gouvernance au sein et entre les cas, nous avons développé un cadre d'analyse multidimensionnel de la performance de la gouvernance. Onze critères ont été définis et renseignés en utilisant des données secondaires issues du diagnostic institutionnel des cas pendant toute la durée de la recherche. Les résultats ont montré que 10 des 11 critères avaient été positivement impactés par l'intervention. Des combinaisons spécifiques de critères et de valeurs de ces critères caractérisaient trois contextes institutionnels typiques observés pendant le processus de construction de la cogestion selon les cas. Trois trajectoires typiques de la performance de la gouvernance ont été caractérisées, incluant des changements graduels et rapides, ce qui montre que les impacts des interventions ont varié en fonction des cas et du temps. La consolidation des changements institutionnels atteints suite aux interventions s'avère nécessaire pour développer avec succès la résilience des systèmes halieutiques à des stress multiples. Cette étude empirique montre que l'expérimentation adaptative est une approche prometteuse pour comprendre la dynamique des institutions coopératives, et ainsi contribuer à développer et rendre durables les régimes de cogestion des petites pêcheries.

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. 2017a). 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 (Ostrom 1986; 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.

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.

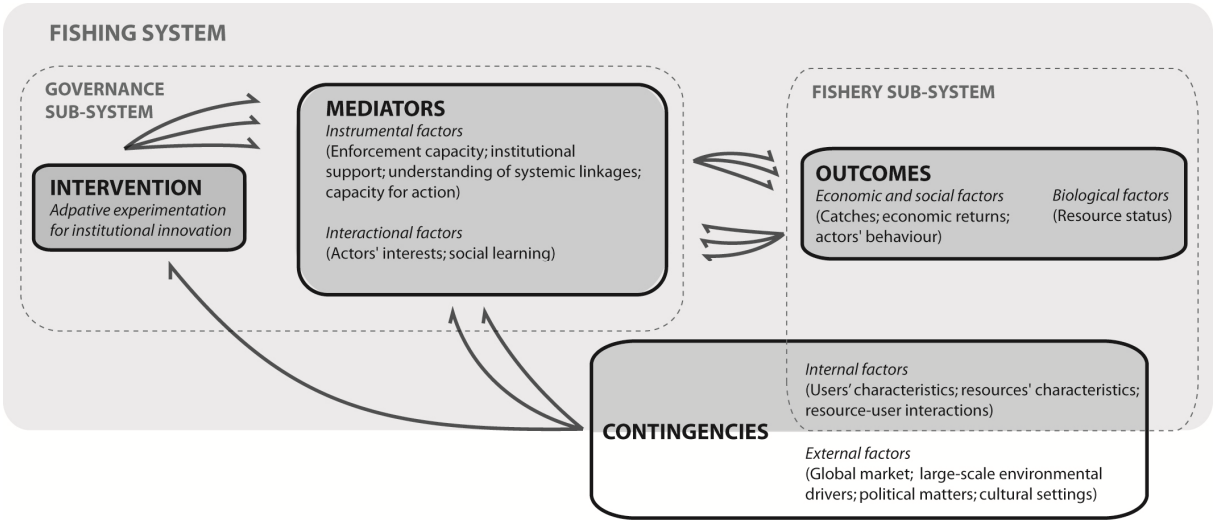

Figure 1. Conceptual causal model of the impacts of an intervention on the fishing socio-ecological system through adaptive experimentation (modified from Stern et al. 2002). Arrows represent the causal relationships within the fishing system, which is composed of a fishery and a governance sub-system, as well as external drivers of change.

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 (Johannes 1981, 1989). 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; David 1994; 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 1998a, 1998b; 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 et al. 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).

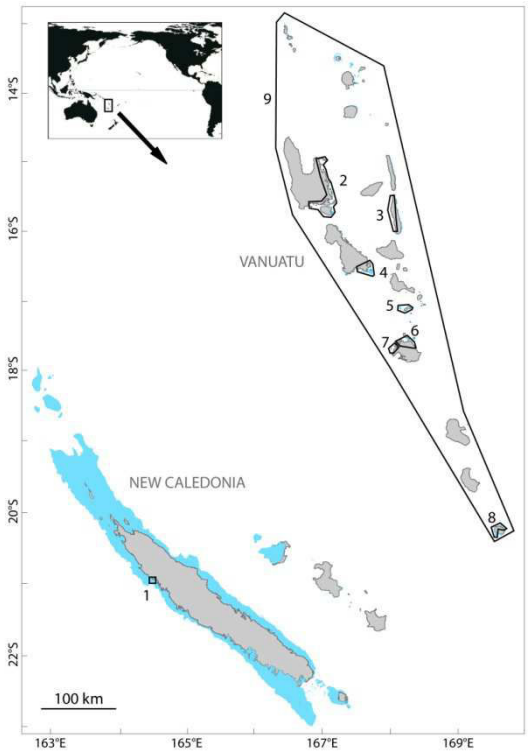

Figure 2. Location of case studies in Vanuatu and New Caledonia, South Pacific. Coral reef areas are represented in blue.

The spatial, social and political scales of the interventions varied across case studies (Table 1). 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 (Table 1). Reef fishing practices in the fisheries considered are organized and operated with limited technological capacities. In each case, sea cucumber fisheries were temporarily closed when our experimentation started due to growth or recruitment overfishing of these resources in previous years. 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 (Table 1).

Table 1. Characteristics of case studies including location, reef fishery rules, sea cucumber fisheries, and adaptive experimentations. TURFs: Territorial Use Rights in Fisheries. NGO: WanSmolBag, a Vanuatu non governmental organization. SPC : Secretariat of the Pacific Community. Purchase price of high value sea cucumber species ranged between US$1/kg and US$5/kg (fresh weight) during the interventions, including *Holothuria scabra* , *H. whitmaei* , *H. fuscogilva* , *Bohadschia argus* , *B. vitiensis* , *Thelenota ananas* , *Actinopyga palauensis* , and *A. mauritiana* .

Characteristics	**Cases**				
	1	2	3	4	5
Location	New Caledonia (Northern province)	Vanuatu (Santo Island, Sanma province)	Vanuatu (Pentecost Island, Penama province)	Vanuatu (Maskelynes Islands, Malampa province)	Vanuatu (Emae Island, Shefa province)
Scale	Local (social unit)	Local (social unit)	Local (social unit)	Local (social unit)	Local (social unit)
Number of communities	2	63	32	11	12
Main occupations (in order of importance to households)	Industry/fishing/agriculture	Agriculture/fishing	Agriculture/fishing	Fishing/agriculture/tourism	Fishing/Agriculture
Legal fishing rules enforced	Minimum harvest size (troca, sea cucumbers), professionnal licencing system, gillnet restrictions, scuba-fishing ban, seasonal closures (fish)	Species ban (sea cucumber 2008-2012, green snail), scuba-fishing ban	Species ban (sea cucumber 2008-2012, green snail), scuba-fishing ban	Species ban (sea cucumber 2008-2012, green snail), scuba-fishing ban	Species ban (sea cucumber 2008-2012, green snail), scuba-fishing ban
Community-based fishing rules in use	TURFs, temporary closure (sea cucumber)	-	-	TURFs, temporary closure (fish), gillnet restrictions	TURFs, marine reserve
Sea cucumber fishery					
Fishing area (surface and depth)	26 km² (0-5 m)	43 km² (0-15 m)	12 km² (0-15 m)	25 km² (0-15 m)	16 km² (0-15 m)
Target species (number)	1 (High value)	15 (Low to high value)	8 (Low to high value)	16 (Low to high value)	15 (Low to high value)
Resource status (assessment year)	Growth overfishing (2008-2016)	Recruitment overfishing (2012 & 2014)	Recruitment overfishing (2013)	Recruitment overfishing (2011)	Recruitment overfishing (2014)
Harvest time and landings (tons)	2008-2016 (753 t)	2014-2015 (57 t)	2014-2015 (4 t)	2014-2015 (105 t)	2015 (58 t)
Intervention					
Action research period	2008-2016	2011-2016	2012-2016	2010-2016	2012-2016
External collaborative organization	IRD	IRD	IRD	Local NGO (from 2010), SPC international scientific and technical organization (2011), IRD	Local NGO (from 2010), IRD

Table 1. (cont.)

Characteristics	Cases			
	6	7	8	9
Location	Vanuatu (Efate Island - northern area, Shefa province)	Vanuatu (Efate Island - southwestern area, Shefa province)	Vanuatu (Aneytium Island, Tafea province)	Vanuatu (all islands)
Scale	Local (social unit)	Local (social unit)	Local (social unit)	National (policy unit)
Number of communities	19	2	7	470
Main occupations (in order of importance to households)	Agriculture/fishing	Agriculture/fishing/tourism	Tourism/agriculture/fishing	Agriculture/fishing/tourism
Legal fishing rules enforced	Species ban (sea cucumber 2008-2012, green snail), scuba-fishing ban	Species ban (sea cucumber 2008-2012, green snail), scuba-fishing ban	Species ban (sea cucumber 2008-2012, green snail), scuba-fishing ban	Species ban (sea cucumber 2008-2012, green snail), scuba-fishing ban
Community-based fishing rules in use	-	TURFs, marine reserve, species ban (giant clam, troca)	TURFs, marine reserve, temporary species ban (giant clam, troca, sea cucumbers), gear restrictions, minimum sale size (lobster)	TURFs, marine reserves, temporary species bans, gear restrictions, and/or minimum sale size across communities
Sea cucumber fishery				
Fishing area (surface and depth)	23 km² (0-15 m)	5 km² (0-15 m)	16 km² (0-15 m)	780 km² (0-15 m)
Target species (number)	17 (Low to high value)	10 (Low to high value)	8 (Low to high value)	20 (Low to high value)
Resource status (assessment year)	Recruitment overfishing (2012)	Recruitment overfishing (2013)	Recruitment overfishing (2013)	Recruitment overfishing (2011-2014)
Harvest time and landings (tons)	2014-2015 (8 t)	2015 (5 t)	-	2014-2015 (602)
Intervention				
Action research period	2010-2016	2012-2016	2012-2016	2010-2016
External collaborative organization	Local NGO (from 2010), SPC international scientific and technical organization (2011), IRD	Local NGO (from 2010), Japan development agency (2012-2014), IRD	Local NGO (from 2010), Japan development agency (2012-2014), IRD	Local NGO, SPC international scientific and technical organization, Japan development agency (from 2010), IRD

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, Table 1). Following this, a similar intervention was developed from 2010 in seven local cases (cases 2 to 8, table 1) and at the national level (case 9, table 1) 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).

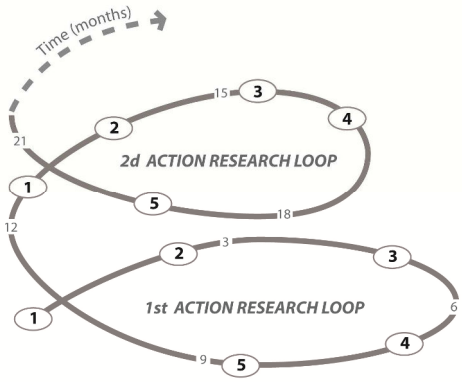

Figure 3. Action research reflexive spiral of the adaptive experimental process (derived from Argyris et al. 1987; Liu 1997; Dickens and Watkins 1999)**.** A typical loop was composed of five collaborative steps: initialization (step 1: e.g., negotiation of ethical issues, the research design, the collective 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 and statistical biomass estimation of the sea cucumber resources 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 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. (2013b, 2013c, 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 2 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 Table 2.

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

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 2. Criteria of the multidimensional assessment framework of institutional performance. Eleven criteria are included: actors' behavior, catches, biomass level and trend in biomass (outcome criteria), enforcement, government support, individual learning, capacity for action, and organization (instrumental criteria), actors' strategies, and collective learning (interactional criteria). The expected change in score during the adaptive experimentation is indicated.

Governance criteria	Performance score (shown as 'levels' ordered from low to high)				Rationale and expected change in score
	Level 1	Level 2	Level 3	Level 4	
Outcome criteria					
Actors' behavior (Behavior)	Most fishers' and other actors' (e.g., private and public sectors) roles are typical of conventional, top-down fishery management and governance.	A minor part of actors (e.g., fishers, private and public sectors) has changed and adapted its practices to the institutional process: between-actor relationships has changed towards better integration of their respective actions and roles in the top-down decision-making process, that is led by fisheries departement officers.	Most actors (e.g., fishers, private agents, and fisheries departement officers) have adapted their practices to the institutional process, including the design and experimentation of new insitutions. They have redefined their respective actions, roles, and relationships within the fishing system, which has changed the local governance regime towards effective co-management.		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)	The biomass of high value species is very low (<2t/km²), which makes the natural regeneration of the resources weak or unlikely.	The biomass of high value species is low (2 to 4t/km²), however that does not put natural regeneration of the resources at risk.	The biomass of high value species is moderate and locally high (4 to 17t/km²). The biomass level of immature and adult sea cucumbers suggests that the resources regenerate at moderate to high rate.		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)	The biomass of high value species is lower than its level when the intervention started.	The biomass of high value species ranges between 1 and 1.3 times its level when the intervention started. Due to statistical estimation uncertainty, the stock is considered unchanged so as to avoid communicating over-optimistic biological outcomes.	The biomass of high value species ranges between 1.3 and 4.6 times its level when the intervention started. The increase in stock is assumed significant.		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)	The fishery is close to collapse : fishing is banned.	Catches of high value species range between 0.35 and 1 times the maximal, unsustainable catch level observed in the fishery. This too high rate corresponds to a non viable exploitation strategy that maximizes short-term gains.	A small fishery has developed. Catches of high value species are smaller than 0.35 times the maximal, unsustainable catch level observed in the fishery, which corresponds to a conservative, sustainable exploitation rate.		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.

Table 2. (cont.)

Governance criteria	Performance score (shown as 'levels' ordered from low to high) Level 1	Level 2	Level 3	Level 4	Rationale and expected change in score
Instrumental criteria					
Enforcement	Individual fishing effort and catches are unenforced in practice. The institutions are not incorporated in local norms. Transgressing the local and/or government rules is not sanctioned in practice by neither public authorities nor communities, although catches and infractions may be monitored.	Public authorities effectively enforce fishing institutions in a timely manner, although infractions may not be systematically reported and sanctioned. Community authorities and fishers are not involved in such a top-down control of fishing activities.	Community authorities and fishers effectively enforce fishing institutions, that are sanctioned according to local norms and values with tacit support from government departments. The latter do not effectively control compliance with fishing regulations.	Fishing insitutions are under the scutiny of local communities and government departments, that jointly enforce them in a timely manner.	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)	Institutions have a formal and legal status, that is endorsed by relevant public agencies at provincial, national or international level. However they are defined without the support of local authorities and fishers.	Institutions are defined by local actors and informally supported by external public actors (e.g., government departments, political representatives), with no specific legal status.	Institutions are defined in conjunction with local actors, private sector, and public authorities that support them through official reglementation.		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	Most actors have limited, fragmented knowledge of the fishing system. There is high uncertainty about the status and dynamics of the resources and appropriate management rules due to multiple factors driving the fishery. There is no common understanding of the problems and potential solutions.	Most actors understand the resource-fisher interactions. They share basic knowledge on resource status and the need for controlling fishing pressure to prevent unsustainable harvesting. However the institutional process is poorly understood, including the expected impacts of rules and payoffs for respecting those rules.	Most actors share a common understanding of the structure, status, and dynamics of the resources, fishing activities, and institutions in the specific social-ecological context, including the institutional process, the expected impacts of rules and payoffs for respecting those rules.		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)	Technical, financial, and political administrative actors' capacities for action are very low and irregularly used as compared with the needs for addressing the fishery problem.	Some technical, financial, and/or political administrative capacities are developed in specific component(s) of the fishing system (e.g., on resources, fishing activities, fishing rules). Overall they are insufficient to address the fishery problem (e.g., lack of relevant, specialized skills).	Relevant technical, financial, and political administrative capacities for action are developed in the fishery and in local and national governance sub-systems. However the use of these capacities does not fit the problem, mainly due to lack of horizontal and/or vertical linkages and/or excessive spreading of capacities across time and/or space.	Relevant technical, financial, and political administrative capacities for action are developed at local and national levels. They are scaled, specialized, rationalized, and coordinated horizontally and vertically to fit the problem in a timely manner.	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.

Table 2. (cont.)

Governance criteria	Performance score (shown as 'levels' ordered from low to high) Level 1	Level 2	Level 3	Level 4	Rationale and expected change in score
Instrumental criteria (cont.)					
Organization	Actors (e.g., fishers, private sector, fisheries department) are not organized to specifically address the fishery problem although ad hoc community-based or governmental decisions may occasionnally constrain fishing activities.	Single-level organization(s) (e.g., fisher organization, government/scientific working group) allow(s) for discussions and collective fishery decision-making. Such formal or informal organization(s) may be facilitated by leaders.	A multi-level organization including government department staff, fishers, and other key actors of the fishery allows for discussions, negotiations, and collective management decisions. This organization may be formal or not.		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)	No specific collective management strategy is observed. Actors including fishers and government departments follow disconnected, possibly conflicting individual objectives.	Some actors including fishers and government departments have adopted a well-defined collective management strategy (e.g., rebuilding stocks), that may be supported by leaders. However some individual actors follow different, conflicting objectives (e.g., short-term catch maximization) that may lead to coalitions opposing the collective management strategy.	Key actors of fishery and governance sub-systems have homogeneous interests and consensual objectives. They have defined a dominant collective management strategy. While there may be a small number of actors with diverging interests, these do not threaten that strategy.		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	Collective, horizontal or vertical interactions between actors of the system are rare. The actors behave using their own experiential knowledge, rather than collective knowledge.	Actors occasionally engage in horizontal interactions through temporary collective actions (e.g., meetings, participative biological monitoring), which allows for exchange of factual and practical knowledge about the local context or external issues. Vertical interactions remain rare.	Actors regularly engage in dynamic, horizontal and vertical interactions through collective actions. These interactions develop collective learning within fishing systems (e.g., understanding of individual interests, trust building, facilitating local conflict resolution) and beyond through between-system knowledge exchange.		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).

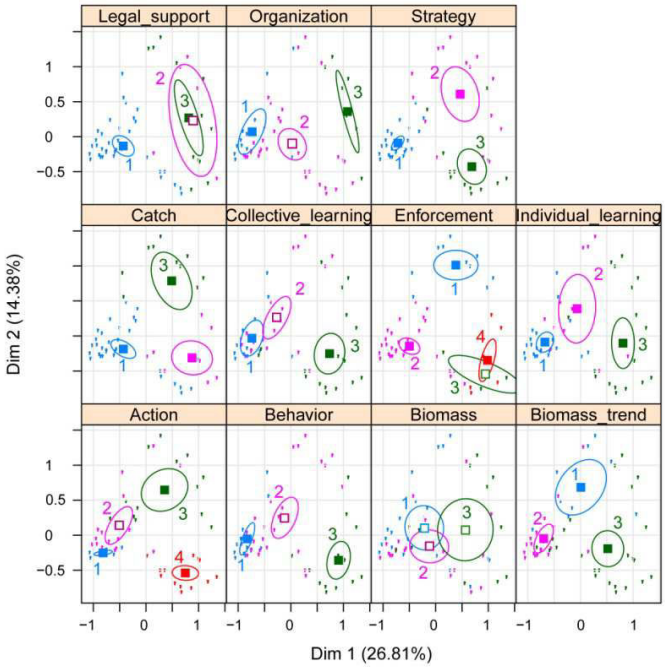

Figure 4. 95% confidence ellipses of the scores of each governance criteria within the main factorial plan of the multifactorial correspondence analysis. Significantly different scores for each criterion are represented by ellipses that do not overlap. Ellipse colors refer to criteria score levels (see Table 2). 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 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 although appropriate knowledge of fishery dynamics was not available (*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 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 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).

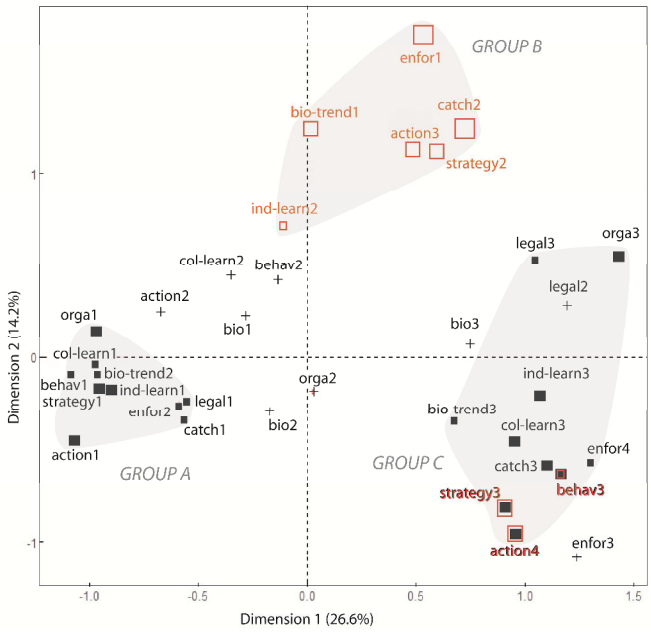

Figure 5. Three institutional contexts emerging from the analysis of institutional performance criteria. Based on the first and second dimensions of the multiple correspondence analysis, significant categories are represented by black (for dimension 1) and red (for dimension 2) squares using a three-level 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). 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 negative cascading consequences on the commitment of most fishers. 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.

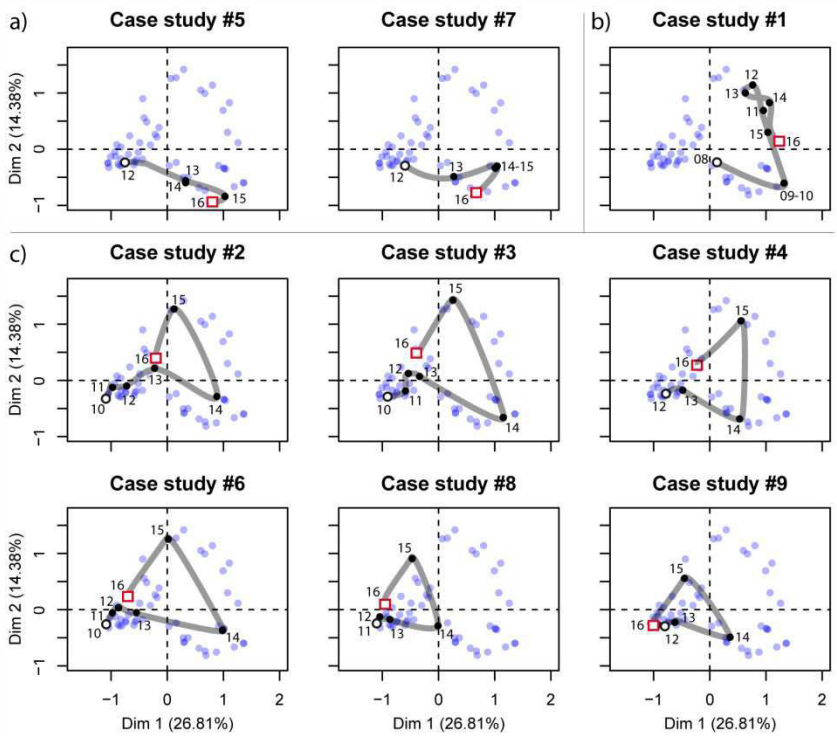

Figure 6. Dynamics of institutional change – A typology. Trajectories of case studies are indicated, represented by their annual institutional performance profile during the experimentation period. Cases belonging to type 1 (a), type 2 (b), and type 3 (c) trajectory are presented. Circles and squares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

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 (Batista et al. 2014). 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 (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 (Crozier and Friedberg 1977; Olivier de Sardan 2005). 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 (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 punctual 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 (Olsson et al. 2007; Abernethy et al. 2014).

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 (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, was an effective way for testing government-supported harvest strategies. 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 several criteria 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 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 (Ostrom 2007; Armitage et al. 2008).

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, 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 (Table 2), 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 the role of bridging organizations or initiatives capable of promoting the organization and participation of horizontal networks of communities in government-supported fisheries co-management institutions seems essential for the cost-effective, successful implementation of small-scale fishery policy interventions (Finkbeiner and Basurto 2015).

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 sustained resilience 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 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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Informations complémentaires du chapitre 2.2.

SUPPLEMENTARY MATERIAL to publication n°4

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1 Action research context

Average export value (constant US$) in the world market of beche-de-mer products significantly increased from US$6-10 /kg in the 1980s-1990s (average: US$7.7 /kg) to US$12-26 /kg in the 2000s (average: US$19 /kg) as many tropical sea cucumber stocks became exhausted in the Indo-Pacific (Figure 1). This rising trend in export value made sea cucumber fisheries highly attractive to traders worldwide, including in Vanuatu and New Caledonia.

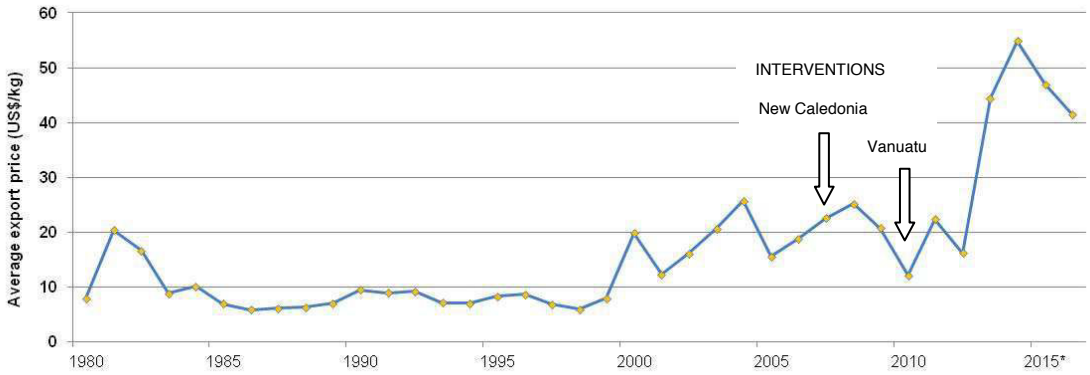

Figure 1. Annual average value per kg of beche-de-mer products exported from Indo-Pacific countries as estimated using FAO data (annual export volumes and values - http://www.fao.org/fishery/statistics/software/fishstatj/en) and GDP deflator of OECD countries (World Bank http://www.worldbank.org/, 2016). * Average export value in 2014, 2015, and 2016 were estimated using official statistics on beche-de-mer exports from Vanuatu.

A formal, scientific and technical partnership has been established between the Northern Province of New Caledonia, the Vanuatu Fisheries Department and the Research Institute for Development (IRD) since early 2011 as part of the government cooperation between Vanuatu and New Caledonia. Both fisheries administrations have elaborated a common strategy for the management of sea cucumber fisheries since 2010 at provincial and national scale, respectively. This strategy has promoted spatial management actions and the participation of local communities in the governance process. The IRD support was coordinated by a fisheries economist (M. Léopold) who was based at the IRD in New Caledonia (2005-2009), at the governmental fisheries department in Vanuatu (2010-2014), and then gradually disengaged from that partnership (2015-2016) following the action research approach.

The objective of this tripartite partnership was to support the implementation of co-management systems for sea cucumber fisheries, as part of fishery policy in both countries. Interventions were conducted in multiple sites and scaled according to the economic value of the sea cucumber fisheries and to the social organization within those sites. Consequently research engagement varied across case studies. Particularly the characteristics and the impacts of the interventions in nine case studies are described below.

2 Case study 1 (New Caledonia, local level)

2.1 Dynamics of sea cucumber resources

IRD supported the management of the *Holothuria scabra* (sandfish) fishery on the Plateau des Massacres, New Caledonia from 2008 to 2016 (see http://cogeron.ird.nc/index.php/fiches-thematiques/cogestion-des-ressources-dholothuries/). Research focused on participative resource assessment methodology and the establishment of a TAC-based co-management regime (TAC: total allowable catches). Resource assessment was based on a direct statistical estimation through stratified sampling, using i) habitat mapping and high resolution satellite imagery, and ii) participative, *in situ* sea cucumber count surveys. The methodology was described by Duvauchelle (2010) and Léopold et al. (2013).

Between June 2008 and June 2016, twelve biological assessments were conducted: 2008 (June, September), 2009 (July, November), 2010 (May), 2011 (March, October), 2012 (April), 2013 (February), 2014 (April), 2015 (June), and 2016 (June). These assessments allowed for estimating the total and legal-sized biomass and abundance of the sandfish resources (Figure 2) and corresponding TACs (Figure 3). In line with the precautionary approach, conservative estimates of these indicators were used to take into account statistical uncertainty.

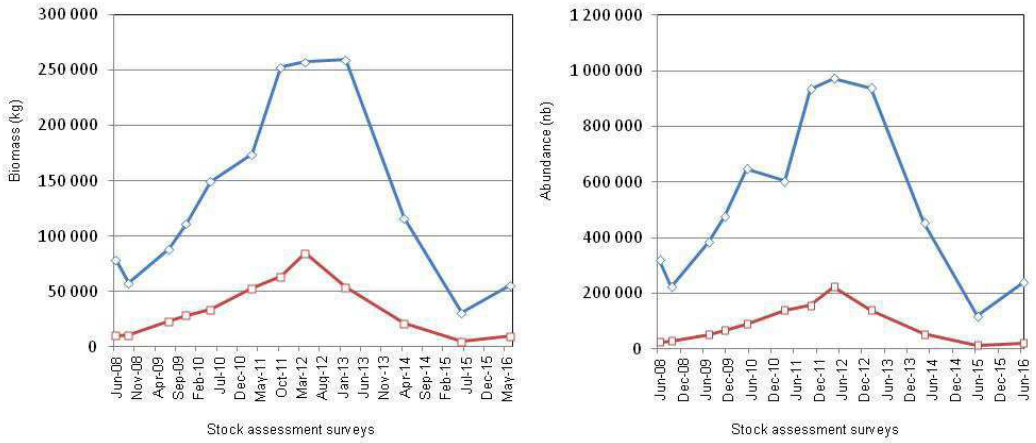

Figure 2. Change in estimated biomass (kg) (left) and abundance (number of sea cucumbers) (right) of the whole stock (blue line) and the legal-sized stock (red line) of sandfish *Holothuria scabra* in case study 1 between 2008 and 2016, based on participative assessment surveys. The intervention started in June 2008.

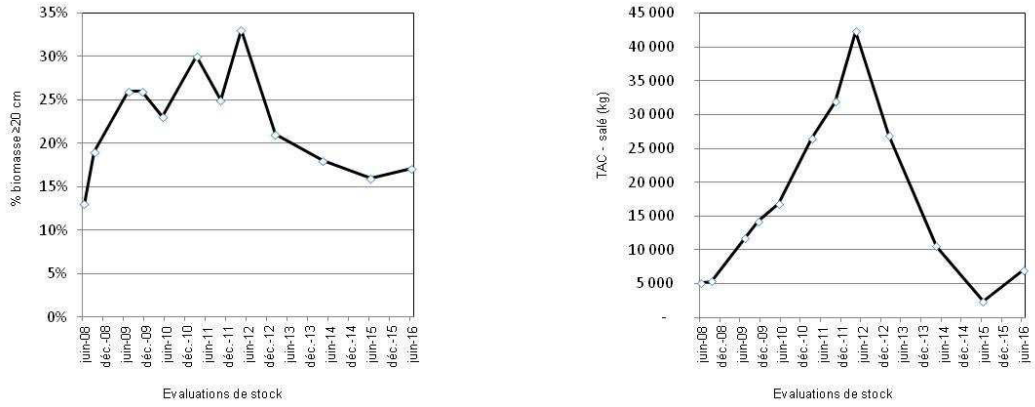

Figure 3. Change in legal-sized biomass as a percentage of the total stock biomass (left) and corresponding total allowable catches (right) of sandfish *Holothuria scabra* in case study 1 between 2008 and 2016, based on participative assessment surveys and catch records. The intervention started in June 2008. Conversion rate from fresh to salt product : 0.523 (Skewes et al., 2004).

The biological monitoring highlighted three successive phases in the dynamics of the resources:

- *Phase 1 (2008- Feb. 2013) of steady stock growth:* in less than five years, the total biomass and abundance of the stock were multiplied by five, reaching nearly 250 tons and one million individuals, respectively. The exploitable stock (consisting of sea cucumbers over 20 cm) increased much faster than the whole stock, reaching 84 tons (x 8) and 224,000 individuals (x 9), respectively. The proportion of legal-sized individuals therefore increased despite a significant decrease in October 2011 and represented up to one third of the total biomass in 2012, reflecting the natural aging process of the resources during this phase.

- *Phase 2 (2013-2015) of strong stock decline*: all the indicators showed a sharp declining trend. In a two year period, the indicators reached lower levels than those of 2008. The biomass dropped by 143 tons (-55%) between 2013 and 2014, and then by 85 tons (-73%) the following year. The average density reached its lowest level (91 individuals/ha) in 2015. This evolution reflected a rapid rejuvenation of the resources and a collapse of the stock.

- *Phase 3 (2016) of slight growth of the stock:* the declining trend of phase 2 stopped and reversed. The indicators clearly increased as in phase 1 (+80 to +100%, except for the exploitable fraction (+ 7% only).

Despite the low abundance levels estimated in 2008 and 2015, the biological monitoring indicates that the sandfish stock was able to regenerate naturally and did not collapse over the period. The density threshold for allowing the natural regeneration of sea cucumber populations (called Allee effect) is not known for tropical species and probably varies between species.

In addition, the indicator trend observed in 2016 indicates encouraging recovery of the resources. If confirmed in the following years, Phase 3 would correspond to a new cycle of resource dynamics and exploitation of the fishery.

2.2 Fishing dynamics

After each resource assessment, a Total Allowable Catch (TAC) was defined based on the biomass of legal sized sea cucumbers (≥20 cm). The fishery was then opened for limited periods of two to three days a week. In parallel with biological monitoring, the fisheries division of the Northern Province has monitored sandfish catches (eviscerated and salted sandfish) since 2008 through two complementary approaches:

i) at landing sites when fishers sold their catch to middlemen and processors: for each open period, the catch by fisher, total number of fishers, purchase price and number of fishing days were recorded. In order to estimate the weight structure of the catches, a random sample of 100 sea cucumbers was additionally weighed for each fisher's catch in 2010 and in 2012.

ii) using buyers' declaration forms: production purchased per fisher and purchase prices were recorded monthly.

The fishery was operated by about 60 fishers of two neighbouring communities. The annual production varied between 6 tons (in 2015) and 110 tons (in 2011) over the period, corresponding to an annual value of €42,000 to €640,000 (Figure 4). The average purchase price varied between €4.2 and €6.7 per kg (salted product), i.e. between €2.2 and 3.5 per kg (fresh weight) (Figure 5).

Three phases – development (2008-2011), declining (2012-2015) and recovering (2016) – were observed in the fishery. Overall these phases corresponded to the resource dynamics (i.e., the catches were proportional to the stock biomass). However, an extremely sharp peak of production was achieved in 2011 (110 tons, + 187% in weight and + 167% in value compared to 2010).

Total cumulative catches over the 2008-2016 period reached 394 tons of salted products (i.e., 753 tons fresh weight) and generated €2,170,000. This outcome showed that the local sandfish fishery could generate significant income for the local communities if properly managed.

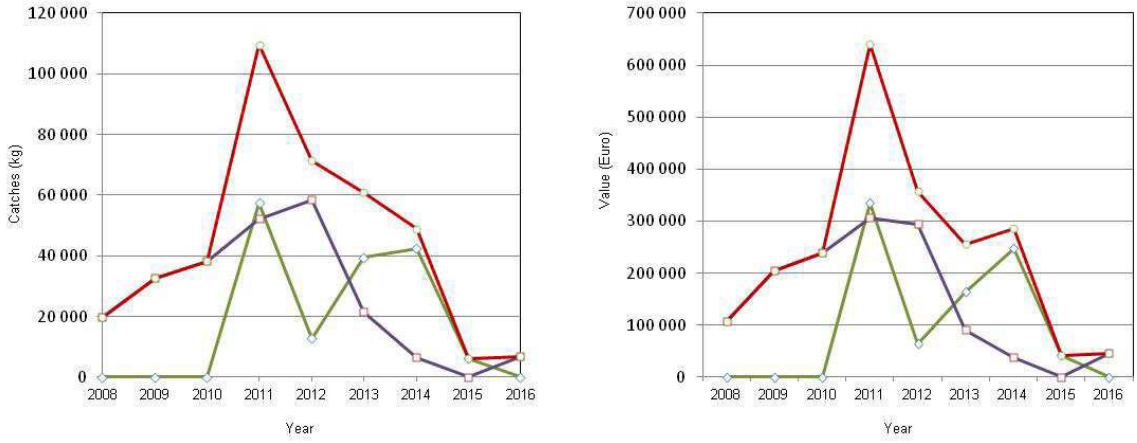

Figure 4. Annual catches (in kg, salted products) (left) and catch value (in Euro) (right) of sandfish *Holothuria scabra* in case study 1 during open fishing periods (blue line), closed fishing periods (green), and in total (red line) between 2008 and 2016. The intervention started in 2008.

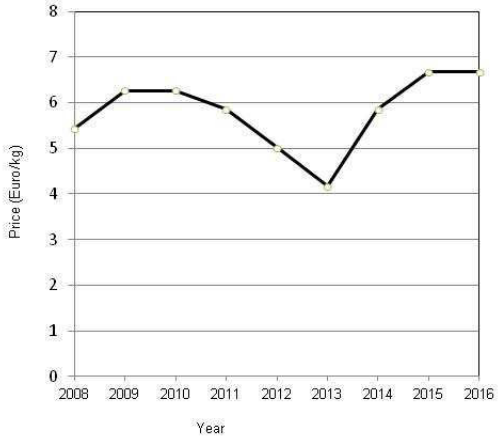

Figure 5. Average purchase price per kg of salted products (in Euro) of sandfish *Holothuria scabra* in case study 1 between 2008 and 2016. The intervention started in 2008.

Catches occurred during closed fishing periods between June 2011 and December 2015, and particularly in 2011, 2013 and 2014 (between 39 tons and 57 tons were sold per year). Particularly fishers did not comply with the closed periods between June and September 2011 (which generated the peak of catches observed that year), and then between September 2012 and December 2015.

The average annual exploitation rate (ratio of catches and total biomass) ranged from 23% to 98%. It was particularly high in 2011 (98%) and 2014 (80%) due to large catches outside opened fishing periods. The largest difference between the total and expected exploitation rates was observed in 2014 (80% and 11%, respectively) when the stock biomass dropped (Figure 3). The lowest exploitation rate was recorded in 2016 (23%).

The average production sold per fisher and per fishing day during the opened fishing periods varied between 20-42 kg/fisher/day in 2016 and 103-178 kg/fisher/day in 2011-2012 (salted

products). A strong linear relationship was observed between the annual legal sized biomass and the annual average catch per fisher and per fishing day (R^2 = 0.81, Figure 6). This result indicated that the stock biomass estimates were reasonably reliable, and that the economic profitability of the fishery (and therefore the attractiveness of the fishery and the opportunity costs of closed fishing seasons) had been significantly increased when the biological level of the resources increased.

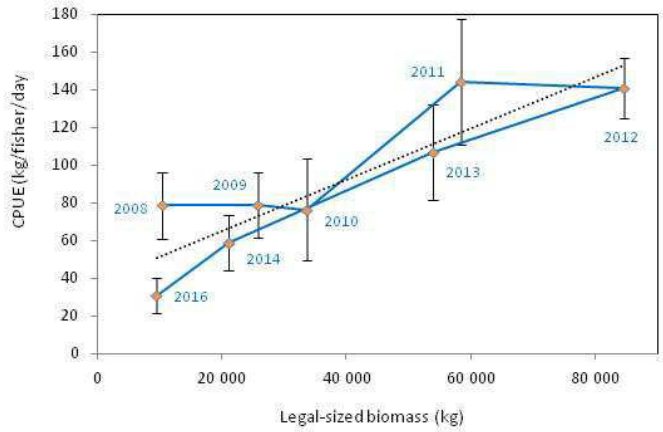

Figure 6. Average catch per unit of effort (CPUE, in kg/fishing day, estimated wet weight) according to the legal-sized biomass of sandfish *Holothuria scabra* in case study 1 between 2008 and 2016. Error bars indicates the standard deviation of average annual CPUE. The linear regression (dotted line) between both variables is represented (y=0.0014x + 37.8, R^2=0.81). The intervention started in June 2008. Conversion rate from fresh to salt product : 0.523 (Skewes et al., 2004).

2.3 Governance dynamics

2.3.1 Informal co-management institutions (2008-2014)

2.3.1.1 Successful TAC-based cooperative management (2008-2011)

The provincial fisheries division has been involved in the management of the small-scale sandfish fishery on the Plateau des Massacres since 2008 following the request of customary leaders and fishers. The latter had indeed noticed a decrease in large sandfish abundance over their territory's fishing grounds and voluntarily decided to ban fishing in 2007 for one year.

The intervention of the provincial fisheries division was designed and implemented with the full cooperation of the fishers and the support of a local leader. An informal TAC-based cooperative management system was experimentally introduced in June 2008 with the collaboration of the IRD (Figure 7). A cost-effective, participative biological monitoring method was developed. The easy-to-use, analytical tool BDMer (http://bdmer.ird.nc/) was also developed and provided to the fisheries division to semi-automatically estimate stock biomass and abundance through statistical inference without external assistance.

High participation in the assessment surveys and compliance with the TACs and other informal rules, including short open periods, showed that the co-management process was

strongly supported locally until June 2011. This generated strongly positive biological and economic outcomes (Figures 2 and 4). The increase in sandfish catches made it possible to decrease total recurrent costs (~€700 per km² including resource and catch monitoring) from 10.9 % down to 1.6 % of the profits from sales from 2008 to 2011. Those costs were covered by the fisheries division while fishers provided in-kind contribution during biological surveys.

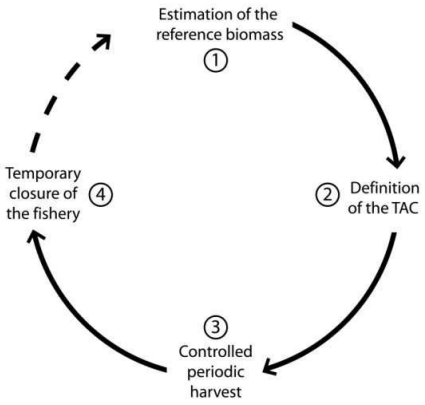

Figure 7. Co-management cycle implemented since June 2008 in the small-scale sandfish *Holothuria scabra* fishery in case study 1.

2.3.1.2 The decline of cooperation (2011-2013)

As noted above, an intensive fishing event occurred between June and September 2011, after the TAC was reached on June 16th and the fishery closed accordingly. A small number of fishers didn't stop fishing for sandfish regardless of the collective decision to close the fishery. They were gradually joined by most of the 60 fishers leading to an abrupt increase in fishing pressure. As a result 57 tons (salted products) of sandfish were sold in three months only, generating nearly €330,000 in gross returns.

Given the proven performance of the TAC-based management system in the area, some fishers sought re-establishing the fishing rules and participated in a stock assessment survey in October 2011. However the efforts of those fishers and the local leader toward respecting the tacit agreement with the provincial fisheries officers and the IRD researchers did not succeed. Fishing for sandfish continued once the TAC was reached and the season closed again in August 2012, which gradually generated conflicts in the communities. Fishers not complying with the institutions relied on kinship relationships and related power to negotiate fishing rights to fulfil their economic objectives. Besides the head of the fisheries division left his position in November 2012, which significantly reduced the capacity for action of that division within the sea cucumber fishery.

Most fishers did not comply with TACs and fishery closures because of compelling economic incentives combined with a lack of public and social sanctions. Indeed the very high fishing yields obtained in 2011 (+ 75% compared to previous years, Figure 4) and in 2012-2013 very likely created incentives for breaking the collective rules. According to fishers' and fisheries

officers' perceptions, the fact that the institutions lacked legal support and legal enforcement was likely the main reason for the downturn of the co-management regime.

As a result co-management was not effective in practice between September 2012 and December 2015. During that period catches occurred regularly proportionally to stock biomass independently of the TACs that were recommended by the fisheries division and the few cooperative fishers. The local leader who actively had supported the co-management process died in 2014.

2.3.1.3 Formalizing co-management institutions (2013-2014)

In order to sustain the very good fishery outcomes achieved until 2012, the provincial fisheries division, cooperative fishers and customary leaders initiated the legalization of the TAC-based co-management system in 2013. It was expected that if legalized, management rules would be effectively controlled and enforced by public authorities.

The *Kan Gunu* organization for sustainable resource management was officially created on October 24, 2014 by the provincial authorities, which established co-management of the sea cucumber fishery in the area (Figure 8). This organization was legally run by a management committee and a technical working group and facilitated by the fisheries division. The management committee included customary leaders, licensed fishers, and representatives of the town councils, political and technical officers of the Northern Province, and police officers. The technical group included all the authorized fishers and technical officers of the Northern Province. The technical group is responsible for:

- Organizing sea cucumber resource assessment of two species, namely sandfish and hairy blackfish *Actinopyga miliaris* through Northern Province's funding;

- Establishing the list of authorized fishers for harvesting sea cucumbers;

- Defining the annual collective TACs for both sea cucumber species and individual TACs per fisher per open period;

- Setting the forecast schedule of fishing and sale days for the whole year; fishing was limited to no more than three consecutive days per month; fishing outside open periods was prohibited and punishable by the provincial environmental code;

- Collecting data on sea cucumber sales;

- Ensuring compliance with the management rules, which included enforcement costs supported by public authorities;

- Proposing changes to this co-management system.

In practice the above formalized management rules corresponded to the informal rules implemented until 2011, which had allowed for rapid regeneration of the sandfish resources and development of the fishery.

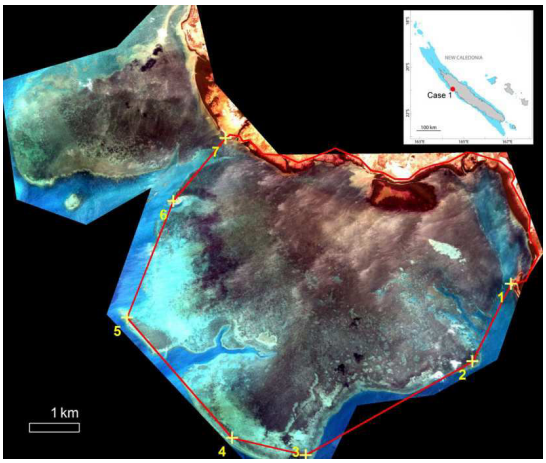

Figure 8. Boundaries of the fishing area (36 km²) governed by the *Kan Gunu* co-management organization for the sea cucumber fishery. Yellow crosses: visual markers of the area.

2.3.2 Operating of the co-management organization (2015-2016)

Once public awareness of the new legal rules had been effective, public authorities patrolled the *Kana gunu* fishing area from early 2015. This included over 18 patrols (one at sea and 17 on land) and seven inspections at the landing sites, which led to four offenders caught for poaching during the closed season, and harvesting undersized sea cucumbers. Three of them did not hold the official fishing license. Some of these offenders had been previously involved in the fishery co-management process and belonged to the same communities as those involved in the *Kana gunu* organization. Following those patrols, the province's vehicles were vandalized during the stock assessment survey in June 2015. Evidence of illegal fishing activities was also reported later in 2015 despite the low stock level, showing that the fishing rules were not fully enforced despite the *Kana gunu* organization.

Despite all the efforts dedicated to effective participation of local fishers in local fishery governance since 2008, some fishers have been questioning the legitimacy of the provincial institution to regulate fishing on their marine tenure. These social conflicts interacted with intergenerational and other social political issues that were external to the fishery, which highlighted the declining power of local traditional authorities and impacted the governance of the sea cucumber fishery. Overall these issues weakened the effectiveness of the co-management organization and increase the management costs of the fishery. The latter were fully supported by the Northern Province as part as its public mandate although fishers provided in-kind assistance for biological monitoring.

3 Case studies 2 to 9 (Vanuatu, local and national levels)

3.1 Fishery governance context prior to the intervention

3.1.1 Management rules and governance system

Between 1980 and 2007, the Vanuatu fisheries department did not enforce any specific regulatory measure to maintain fishing pressure at a sustainable level, although minimum size limits were defined for a few species in 2005. Sea cucumber resources were considered a single stock although 23 commercial species were likely harvested (Table 1) and distributed in over 80 islands of the archipelago, spreading over ~1200 km. Before the 2000s, little information was indeed available on the high vulnerability of tropical sea cucumber species to overexploitation due to their specific biological and ecological characteristics.

Table 1. Commercial sea cucumber species observed in Vanuatu waters. Commercial value is indicative of purchase prices per kg (wet weight) recorded in Vanuatu during this research. High value species *** (US$1-5 per kg); medium value species ** (US$0.4-0.8 per kg); low value species * (US$0.1-0.3 per kg).

Scientific names	English names	Bislama names	Commercial value
Holothuria fuscogilva	White teatfish	Waet titfis	***
Holothuria whitmaei	Black Teatfish	Blak titfis	***
Holothuria scabra	Sandfish	Sanfis	***
Actinopyga palauensis	Deepwater blackfish	Dipwota blakfis	***
Bohadschia vitiensis	Brown sandfish	Braon sanfis	***
Bohadschia argus	Tigerfish	Taikafis	***
Actinopyga mauritiana	Surf redfish	Sefredfis	***
Thelenota ananas	Prickly redfish	Paenapolfis	***
Actinopyga miliaris	Hairy blackfish	Blakfis	**
Stichopus vastus	Brown curryfish	Braon karifis	**
Stichopus chloronotus	Greenfish	Krinfis	**
Stichopus herrmanni	Curryfish	Karifis	**
Stichopus horrens	Peanutfish	Pinatfis	*
Bohadschia marmorata	Chalkfish	Jokfis	*
Holothuria atra	Lollyfish	Lolifis	*
Holothuria coluber	Snakefish	Snekfis	*
Holothuria edulis	Pinkfish	Pinkfis	*
Holothuria flavomaculata	Red snakefish	Red snekfis	*
Holothuria fuscopunctata	Elephant trunkfish	Elefenfis	*
Pearsonothuria graeffei	Flowerfish	Flaoafis	*
Actinopyga lecanora	Stone Fish	Stonfis	*
Thelenota anax	Amberfish	Ambafis	*

Additionally no information was available for setting sustainable levels of fishing pressure. A unique “fish export processing establishment license” was issued by the fisheries department at the fixed rate of VT100,000 per year (~US$1,000) to any company involved in the industry for processing and exporting beche-de-mer products. However no government restriction applied to the number of operating companies that used joint venture agreements (although foreign interests usually owned the larger proportion of the shared agreements). Therefore the delivery of processing and export licenses and export permits did not impose any capacity or operating limitations within the sea cucumber fishery until 2007, although the use of scuba and hookah equipment for commercial fishing of sea cucumber was not allowed nor reported.
Nevertheless some rural communities established temporary bans for sea cucumbers on a voluntary basis at the local level. The objective was to allow for stockpiling resources in their marine tenure for several years. Although most of these contemporary taboos did not

eventually prevent overexploitation of sea cucumbers due to too high demand, local socioeconomic needs, and fisheries being reopened, they reflected the type of harvest strategy (i.e., spatial temporary closure) that would be acceptable by communities.

Since the abundance and diversity of sea cucumber species depend on reef habitat type and surface, these vary greatly throughout the archipelago, as fishing grounds are heterogeneously distributed. Harvest was conducted by local communities (male and female) over each community's marine tenure.

Sea cucumber catches were only monitored at export gates at Luganville and Port-Vila through export permits delivered by the Fisheries Department, that provided basic national fishery statistics for all species combined. These statistics may underestimate real catches since underreporting likely occurred particularly in the 1980s and the 1990s. Monitoring of fishing activities, processing and shipment of products within the country was ineffective due to lack of capacity and planning. Consequently no precise information was collected on fishing areas, respective catches, and landing value of sea cucumbers during that period.

3.1.2 Trends in beche-de-mer export volume and value since 1980

According to official statistics, total bêche-de-mer exports increased rapidly from six tons in 1983 to 48 tons in 1997 (average: 28.2 tons/year), peaking at 66 tons/year in 1992 and 1994, and steadily declined to seriously low levels during the mid-2000s (average: 18.6 tons/year) (Figure 9). This "boom and bust" trend suggests that sea cucumber stocks had dramatically declined since the late 1990s throughout the country. Similar trends in sea cucumber catches were observed in a number of countries in the Pacific region, which also supports this hypothesis although no biological data is available to confirm it.

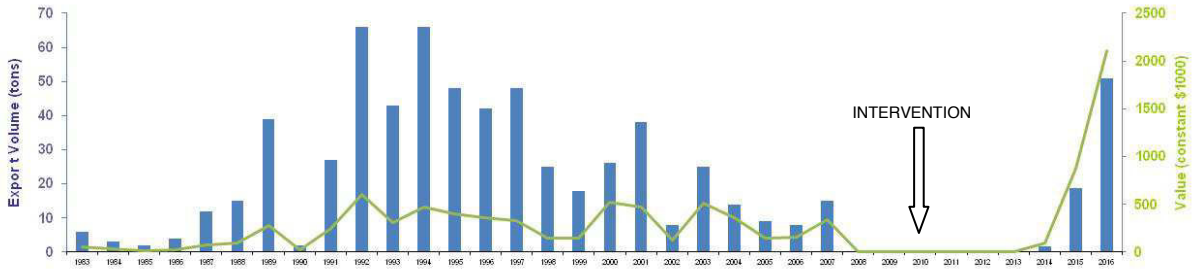

Figure 9. Vanuatu bêche-de-mer export volume and value per annum from 1983 to 2016. Export volume over the period and export value between 2014 and 2016 was based on fisheries department's data. Export value (in constant US$) from 1983 to 2007 was estimated using FAO data (annual export volumes and values - http://www.fao.org/fishery/statistics/software/fishstatj/en) and GDP deflator of OECD countries (World Bank http://www.worldbank.org/, 2016).

The trend in annual value of Vanuatu bêche-de-mer exports can be explained by the higher value of bêche-de-mer in global markets in that period, which compensated for the strong decline in catches in Vanuatu in the early 2000s (Figure 1). In the management context that prevailed between 1980 and 2007, the Fisheries Department let the market take its course. Consequently, as the demand strengthened, higher prices were paid to fishers resulting in a dramatic increase in fishing effort. Strong commercial incentives led to increasing fishing pressure on sea cucumber resources despite clear signs of overexploitation (and very likely low catch rates) in the late 1990s (Figure 1).

The free access, market-driven strategy eventually resulted in stock collapse in most islands of Vanuatu in the mid-2000s although this trend was hidden by the short-term profit from the fishery. Catches collapsed in the early 2000s. The fisheries department therefore unilaterally established a 5-year national moratorium on January, 1st 2008, before the intervention started. The objective of the national ban was to allow for regenerating sea cucumber resources. Some neighbouring countries (e.g., Papua New Guinea, the Solomon) followed the same government strategy during that period.

3.2 Phase 1 of the intervention (2010-2014)

3.2.1 National moratorium (2010-2013)

The national moratorium was extended for another 5 years in January 2013 based on biological assessments that showed slow recovery of the resources. However, the ban prematurely ended in February 2014 due to commercial pressure, as explained below.

Consequently the sea cucumber fishery remained closed for six years. The national closure was effectively enforced despite anecdotal reports of illegal exports of small quantities of beche-de-mer at Port-Vila international airport during this period. The national ban therefore resulted in effective conservation of sea cucumber resources in all islands of Vanuatu during six years (2008-2013).

From 2010, the fisheries department requested the assistance of regional scientific organizations (the IRD and the Community for the South Pacific - SPC) to implement research activities for assessing i) biological impacts of the national closure on sea cucumber resources, and ii) appropriate management measures to sustain the fishery when the moratorium is lifted, as part of the drafting of a national management plan for sea cucumber fisheries.

The stock of 20 sea cucumber species was assessed in seven islands of Vanuatu (totalling twelve fishery sites in the main past fishing grounds) by the fisheries department with the scientific assistance of the IRD, the Northern Province of New Caledonia, and the SPC between September 2011 and September 2014 (Figure 10). A cost-effective, participative survey method was specifically designed based on Léopold et al. (2013). Surveys were conducted with the assistance of local fishers and WanSmolBag resource monitors in those sites. Awareness concerning stock status was provided to communities immediately after surveys using BDMer tool for statistical analysis. In case studies 4, 5, 6, 7, and 8, the fisheries

department regularly informed communities of the ongoing management strategy during other project activities that were conducted in those sites.

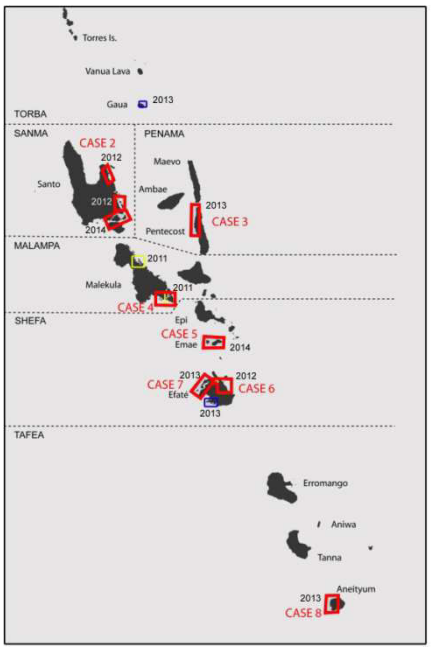

Figure 10. Sites of sea cucumber fishery management in Vanuatu. Local case studies (in red) and biological survey years are indicated. Outlined areas outside local cases were part of the national case study.

In total the costs for conducting biological surveys in these sites reached about US$80,000 and were covered by the fisheries department through the Government Development Fund and external aid from France, New Caledonia, and European Union. Survey costs ranged between US$2,000 and US$5,000 per site depending on how large and remote the fishing grounds were. Total development costs for the BDMer tool were US$23,000.

Stock size of commercial species greatly differed among sites and among species. Overall low abundance of very high value species (black teatfish, white teatfish, and sandfish) were observed in most fishing grounds while low to medium value species were generally present at higher abundance (Figure 11). Notably moderate stocks of black teatfish were observed in Emae (case 5) and Aneityum (case 8) islands. This encouraging trend highlighted positive effects of the fishing ban. However white teatfish and sandfish were likely close to local extirpation in the survey sites.

These results had important consequences concerning the management of sea cucumber resources. First, fishery regulations should be defined by species and by area to avoid serial depletion of fishing grounds. It was predicted that national open season or national TACs would lead to serial overexploitation of sea cucumber resources.

Second, biological surveys allowed for detecting encouraging, positive effects of the 5-year ban on sea cucumber stocks (2008-2012). However, small stocks were still being observed in most sites – a strong incentive for the fisheries department to maintain control over the fishery, since the moratorium was found to be too short to allow the full recovery of sea cucumber resources (except for few species in some islands).

The fisheries department therefore decided in January 2013 to extend the moratorium for 5 years more, as a precautionary approach. Research assisted the Vanuatu government through the regional fisheries technical advisory committee of the Melanesian spearhead group countries in April 2013, because it was expected to strengthen critically-required, national political support for implementing the national management plan for sea cucumber fisheries.

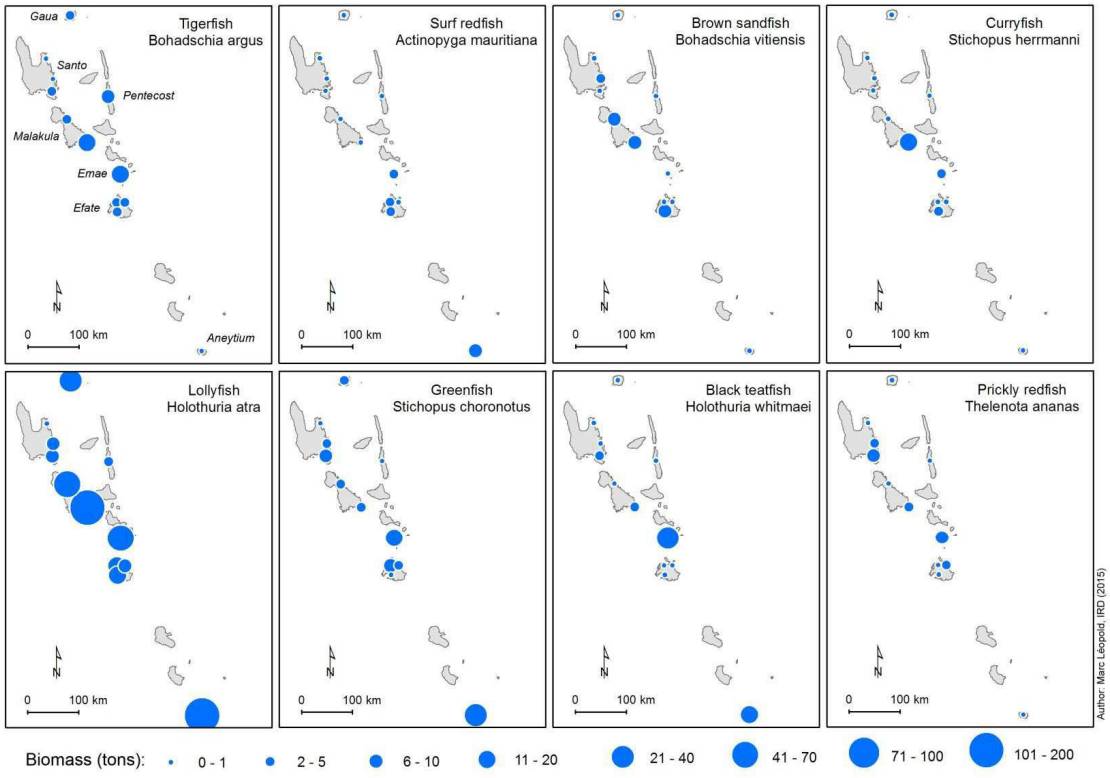

Figure 11. Stock biomass (in tons) of the most abundant sea cucumber species in the 12 survey sites of Vanuatu. Refer to Figure 10 for local case sites. Assessment areas outside local cases were part of the national case study.

3.2.2 Experimental TAC-based co-management (2014)

To comply with Fisheries Act No 10 of 2014 (Part 4, sections 10-11), sea cucumber fisheries were identified as "designated fisheries" due to their high commercial value at a national level. The overall objective was to rebuild sea cucumber stocks while maximizing profit for Vanuatu communities in the long term. To set and control fishing pressure at sustainable level in all fishing grounds, the principles of the national management strategy were threefold:

1) Implementing the precautionary approach, in accordance with Part 2, section 4 of Fisheries Act No 10 of 2014 (given past collapse and slow recovery of sea cucumber resources in Vanuatu).

2) Implementing the co-management approach, by ensuring that fishers (male and female) and customary right holders contribute to the decision-making process at a local scale (e.g., by participating in data collection, having access to survey results, setting local fishing and sharing rules). This aimed at enhancing local stewardship and compliance with the future national management plan.

3) Implementing the adaptive approach, by ensuring that fishing pressure is set at sustainable level according to resource status in respective fishing grounds.

Unexpectedly the fishery was re-opened by the fisheries department in 2014 due to very strong commercial pressure. An experimental rotational harvest strategy was successfully trialled in 2014 at a national level. Strict conditions applied in authorized harvest areas in accordance with Fisheries Regulations Order No. 11 of 2014 as presented below. Low catches were allowed in pilot areas to trial the drafted management plan as well as to provide extra income for communities in areas where the stock biomass had been estimated.

To prevent resource depletion, the TACs were established by species and by area. All the sea cucumbers that had reached the legal catch size were included in the species-specific TACs in each authorized area based on survey results. Also these TACs did not exceed 30% of the total stock per species so as to prevent overharvesting if few juveniles or sub-adults had been recorded during biological surveys. As a result, the TACs consciously underestimated catch volumes. They were readily accepted by local communities. The TACs were expressed in tons of live sea cucumbers so as to allow direct on-site monitoring. The fisheries department also reviewed minimum catch sizes for 23 sea cucumber species based on available knowledge in scientific literature.

Based on available knowledge and action capacities, the fisheries department authorized nine species for harvest in 2014 in seven management areas in Santo (case 2), Pentecost (case 3), Malekula (case 4), and Efaté (case 6 and 7) islands (Figure 12). A total of 27 species-specific TACs were set for a total of 45 tons (wet weight). No TAC exceeded 6 tons and half of them were below 1 ton, highlighting how low overall stocks were in 2014. TACs were set conservatively to prevent overexploitation.

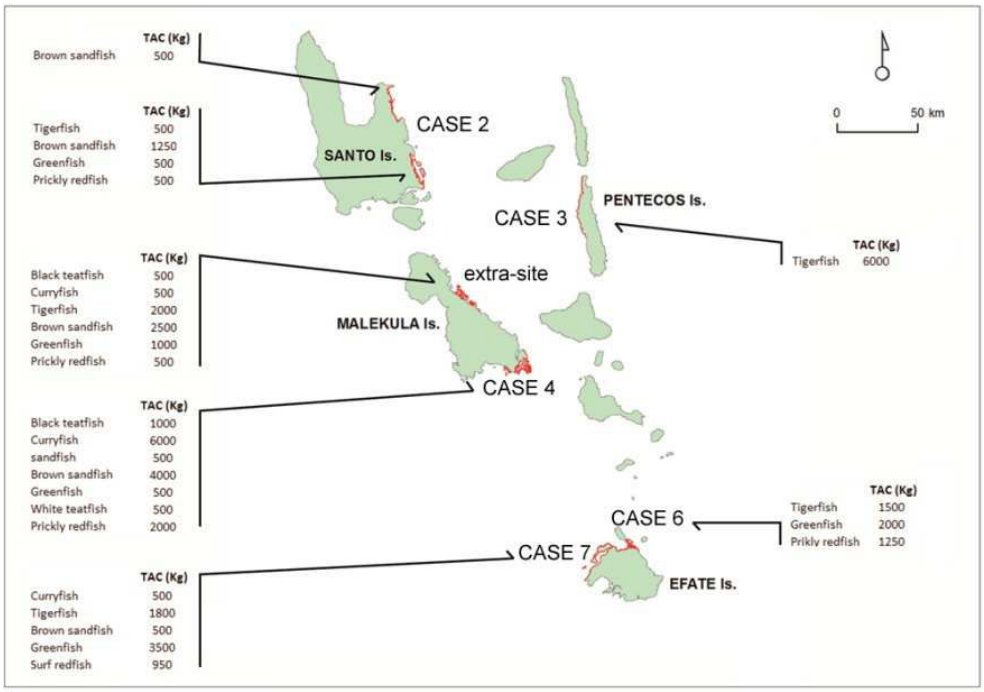

Figure 12. Pilot co-management areas (n=7) where restricted harvest of sea cucumber was authorized in 2014. TACs of authorized species set in each area (wet weight) and reef areas (in red) are shown.

Licensing, catch monitoring and enforcement of fishing rules also applied. Three companies were granted processing licenses to operate in the authorized areas. Two companies were licensed in each authorized area and equitably shared the TACs.

Fishing was allowed in each area for a very short time (one to several days) to facilitate joint monitoring of the TACs and feedback to fishers. A fisheries officer was present during harvest to enforce size limits and monitor catches per species on-time. Undersized sea cucumbers were returned to sea alive. On-site catch monitoring costs were paid for by the three operators as a condition of their license. Two companies fully complied with this condition while the other company did also purchase sea cucumbers in the absence of a fisheries officer.

Total catches eventually reached 20 tons (wet weight) in authorized areas in 2014. Catches only kept within TACs if a fisheries officer was on-site to supervise landings. When on-site checks were not carried out by a government officer, unauthorized catches (i.e. exceeding TACs or harvest of prohibited species) were found to have occurred. In total, unauthorized catches reached 8 tons (wet weight), reported in Malekula and Efate islands.

According to the fisheries department's records, first sale price greatly varied among species, buying companies, and communities (between ~US$0.4 and US$4 per kg, wet weight). First sale price averaged around US$1 per kg wet weight, for all species together (~ US$12.5 per kg dry weight using an average wet-to-dry conversion rate of 8%). Although the first sale price of high value species was occasionally considered too low by fishers, the average first sale price (all species together) could be considered reasonably fair given that the TACs were

mostly composed of low to medium value species. The total first sale value of catches was estimated at about US$20,000. The export value of sea cucumber species (dry products) ranged between US$10 and US$110 per kg and averaged US$62 per kg all species together. The total export value of catches was estimated at ~US$100,000. This value was low compared both to management and operating costs.

License fees and management and operating costs were assessed. Given its modest recurrent budget allocations, the fisheries department used the "user-pays principle" and additional economic consideration for setting license fees. Any person or company involved in the sea cucumber fishery contributed t*o meet the management costs* of the plan. The fisheries department funded other management costs (e.g., permanent staff wages) while communities made payment in-kind by taking part in the stock assessment surveys.

The annual license fee was set proportionally to the amount of sea cucumber authorized for processing. It was established at US$1 per kg wet weight. Despite this high license fee, three companies purchased 17.7 %, 28.8 %, and 53.5 % of total TACs, respectively. Total license fee revenue reached US$45,000 for all TACs (45 tons wet weight) in 2014. This accounted for less than 60 % of the expenditures of the fisheries department to manage the fishery from 2011 to 2014. This cost recovery rate was due to fixed assessment costs on the one hand, and to very low TACs on the other hand. It was considered too low to sustain fishery management given the low recurrent budget of the fisheries department.

The total export value of TACs (~3.6 tons of beche-de-mer) was estimated at around US$150,000. Export value on the world market of beche-de-mer averaged ~ US$42 per kg (dry weight) in 2013 (Figure 1). Because TACs were mostly composed of low to medium value species, license fees represented about 30 % of total export value, which was considered too high and unfair by the industry. Indeed the processing companies did not fully harvest their TACs during the license year, which yielded a gap in terms of their desired and achieved profit margins. Total catches represented only 43% of total TACs. This gap was partly predictable for two main reasons. First, the lifting of the moratorium due to strong market demand had not been anticipated by the fisheries department, which resulted in late license granting in 2014 and shortened the fishing season. Second, local conflicts often emerged due to disputed arrangements between companies and communities (e.g., resource ownership issues, unfair product pricing) which delayed or sometimes prevented harvest in the sites authorized by the fisheries department.

Overall the trial of the harvest strategy was very informative and conclusive. Feedback from communities concerning the TAC system and the necessary involvement of the fisheries department for controlling harvest on-site were very positive. Communities endorsed that the presence of a fisheries officer should be a condition for opening harvest in their fishing grounds. Providing comprehensive awareness to communities prior to harvest (e.g., concerning management rules, pricing, and licensing) was mandatory to avoid local conflicts

and set fair commercial arrangements. The fisheries department was able to define procedures for generalizing the species-specific, TAC-based system at a national level as part of the NMPSCF. Results showed that a rotational pulse fishing strategy would be required in Vanuatu in order to 1) reduce operating costs and increase profits, 2) contain the costs of TAC monitoring in each open area, 3) avoid diluting the human and financial resources available for stock assessments, and 4) ensure high compliance with fishery restrictions.

In order to make harvesting more profitable and sustainable, it was also recommended to authorize future fishery openings rationally, based on stock levels, species-specific TACs and expected profit. For instance, harvesting may be authorized only once every two to five years in each area if TACs exceed a pre-defined threshold (e.g., 2 tons), while processing could be limited to just a few licensed companies. To recover management costs, license fees, an export levy and/or a specific management fee should be fairly set by the fisheries department owing to the attractive, commercial nature of the fishery.

3.3 Phase 2 of the intervention (2015)

3.3.1 National management plan for sea cucumber fisheries

In accordance with the recommendations following experimental harvest in 2014, a 5-year national management plan for sea cucumber fisheries (NMPSCF) was finalized in early 2015 and endorsed by the Ministry of Agriculture, Livestock, Forestry, Fishery, and Biosecurity on July, 10th 2015. The NMPSCF was considered a significant, collective achievement by the fisheries department. Indeed the harvest and management strategy was conscientiously defined based on the fisheries department's capacity and experience, the 4-year expertise contribution of the IRD and SPC (2011-2014), and the positive feedbacks of multiple communities in the case studies. It had also been discussed at the Heads of Fisheries (HOF) meeting at SPC headquarters in 2012 and within the Fisheries Technical Advisory Committee (FTAC) of the Melanesian Spearhead Group countries in 2013.

The harvest and management strategy of the NMPSCF was defined as follows (Table 2):

1) The fishery was to be managed under an indefinite closure with short open seasons based on a rotational system;

2) During open seasons, a system of TAC was to be applied for each species and fishing area. TACs were indeed easy to understand by communities;

3) Additional management guidelines and specific measures aimed to addressing data deficiency issues, observers' roles, applied research needs, fishing rights and access to community marine areas, and gear restrictions.

Table 2. Fishing rules included in the 5-year National management plan for sea cucumber fisheries in Vanuatu (NMPSCF) 2015-2020.

	Fishing rules
1	Establish permanent fishery closure: limited open fishing season, authorized areas, and TAC will be declared by the fisheries department when the resources stocks have recovered to healthy stock levels;
2	Establish licensing arrangements to control and monitor sales, processing and export of sea cucumber products;
3	Restrict fishing methods and gears for the collection of sea cucumbers (e.g., no use of scuba and hookah equipment, no use of "bombs");
4	Restrict the collection of certain sea cucumber species whose biological sustainability is deem to be threaten by fishing activities (e.g., white teatfish and sandfish);
5	Strengthen monitoring of resources, catches, purchases, processing, exports of sea cucumbers to support management;
6	Establish an effective enforcement system to ensure compliance with the plan, including conditions of licenses and fishing regulations;
7	Establish an effective public awareness program to provide feedback to communities on the status of stocks and economic benefits derived from the fishery;
8	Restrict licensing to indigenous Ni-Vanuatu-owned (or over 52% shareholding) processing companies;
9	Restrict traditional processing of sea cucumber to increase value adding through high-grade processing and exporting final products;
10	Establish the Fisheries Management Advisory Council (FMAC) in accordance with Section 9 of Fisheries Act No. 10 of 2014, to provide recommendation to the fisheries department on the management, development and conservation of the sea cucumber fishery.

3.3.2 Nationwide fishery opening

Despite the NMPSCF being established, external contingencies led to a short nationwide fishery opening of the sea cucumber fishery in September 2015. Indeed major natural disasters severely impacted urban and rural areas throughout Vanuatu in 2015. After class 5 tropical cyclone Pam hit the country on March, 13th 2015 destroying thousands of homes and gardens, the El Niño-fuelled drought caused additional serious damage on recovering food crops including coconut plantations and household livelihoods (e.g., water shortage, drop of income from primary sector) in most islands. In this crisis context, socioeconomic needs of communities exacerbated fishing pressure on commercial marine resources such as sea cucumbers for generating income in the very short term. This contextual social demand for cash was actively and opportunistically supported by beche-de-mer traders and the local industry.

As a result of intense pressure from communities, companies, and political leaders, the fisheries department urgently opened the sea cucumber fishery, which was used as a critical safety net. In accordance with Fisheries Regulations Order No. 120 of 2015, the Fisheries Department declared a 4-month open season for sea cucumber harvest in seven islands on August, 27th 2015. The open season lasted from September, 1st 2015 to December, 31st 2015.

As endorsed by Fisheries Regulations Order No. 120 of 2015, the fisheries department made the following changes to the just-released NMPSCF:

1) Areas that had not been previously surveyed by the fisheries department were opened to fishing, so as to expand the number of beneficiary coastal communities. Many additional islands were harvested although no open season had been declared by the fisheries department (Figure 13). No biological data on sea cucumber resources was available in these islands prior to harvest;

2) Species-specific TACs were consequently not based on stock assessment data. Instead they were set arbitrarily at island level in order to reach a total allowable catch that was considered economically acceptable by the fishery sector and ecologically sustainable by the fisheries department. Overall total TACs reached 21 tons of beche-de-mer, for all species together. However the species composition and the harvest sites markedly varied between recommended and authorized TACs. Indeed the recommended TACs only included the species that were observed at reasonable legal-sized biomass levels. They were therefore mainly composed of low value species such as lollyfish (78 %). On the contrary authorized species also included high to medium value species that were observed at low density and/or mainly composed of small individuals (e.g., white teatfish, prickly redfish, black teatfish, and surf redfish);

3) Species-specific TACs were set in dry weight instead of wet weight, which made the on-site control of TACs unenforceable by fisheries observers and authorized officers (see below);

4) No restriction applied on the number of sea cucumber processing licenses due to the very strong commercial pressure of local investors;

5) Due to time limitations, the Fisheries Management Advisory Council (FMAC) was not consulted for advice for drafting Fisheries Regulations Order No. 120 of 2015 or declaring the fishery open season.

Before and during the open season, processing companies actively canvassed communities including in locally-closed marine areas and unauthorized islands. This generated strong local economic expectations throughout the country as well as local conflicts (e.g., between fishers, chiefs, elders, and/or WanSmolBag resource monitors) due to divergent views on harvest and management strategy in some communities (e.g., in Efaté (case 6 and 7), Emae (case 5) and Aneytium (case 8) islands).

The resulting harvest strategy was a nationwide 4-month fishery opening from September, 1st to December, 31st 2015. The technical breach of the national management plan had dramatic consequences on compliance with catch limits as described below.

3.3.3 Operating conditions of the fishery

3.3.3.1 Fishing and processing practices

Since sea cucumber fishing grounds were located in remote areas and local communities lacked the capacity for processing sea cucumbers, harvest activities were initiated and driven by processing companies. A total of 17 processing companies were licensed for operating during the open season while another processing company operated throughout 2015 using a two-year research permit granted by the fisheries department in 2014. Although these licenses were held by Ni-Vanuatu nationals, joint partnership arrangements allowed foreign investors to partner with local Ni-Vanuatu interests and to operate in processing sites. Some of these companies simultaneously operated processing facilities in multiple islands in order to maximize sea cucumber purchase before the fishery was closed. Rudimentary processing facilities were established by companies in most islands close to main fishing areas for boiling and drying sea cucumbers.

Between-site shipments of fresh or partly processed sea cucumbers were also organized to minimize operating costs, which raised catch monitoring issues (see below). Partly processed products were aggregated and then shipped to Port-Vila or Luganville for reprocessing to fully-dried products. Inspection of processing establishments was conducted by the seafood verification agency of the fisheries department or fishery observers to prevent any risk of contamination of products and the environment (e.g., through water waste).

As a result, harvesting was simultaneously encouraged in dozens of fishing areas in the six provinces of Vanuatu, which raised dramatic monitoring and compliance issues (see below). Sea cucumbers were eventually harvested in all islands of Vanuatu by the end of 2015, except in Aneytium island (case study 8) and in a few small islands with low sea cucumber resources (Aniwa, Futuna, Paama, and Tongoa islands) (Figure 6). In Aneytium island, the sea cucumber harvest was locally banned by customary chiefs following the fisheries department's advice in 2014.

Communities frenetically engaged in sea cucumber fishing as long as companies operated in their area. Fishers included most people (male and female) from age ~15 to ~60. Female and old fishers mainly gleaned shallow species on fringing reefs and flats at low tide while young and middle-age men practiced breath-hold diving in deeper areas (1-10 m). The use of "bombs" (heavy lines with hook) was occasionally reported for catching high value individuals (e.g., white teatfish) in deeper waters (<15 m). This resulted in intense fishing pressure in all inshore areas (0-15 m depth) in which the licensed companies operated.

Island-based catch limits were not enforced except in the southwest coast of Efaté island (case study 7). Licensed companies depleted resources with no concern for the future, since they did not plan to harvest sea cucumbers in the same reef areas in coming years. In practice buyers provided powerful incentives to harvest sea cucumbers as quickly as possible before the fishery was closed again. This strongly exacerbated fishing pressure. Buyers stopped purchasing sea cucumbers in communities when average size and daily catch rates of sea cucumbers dropped to non-profitable levels. This strategy suggests that resources were strongly depleted in all the areas visited although there is no biological data to confirm it.

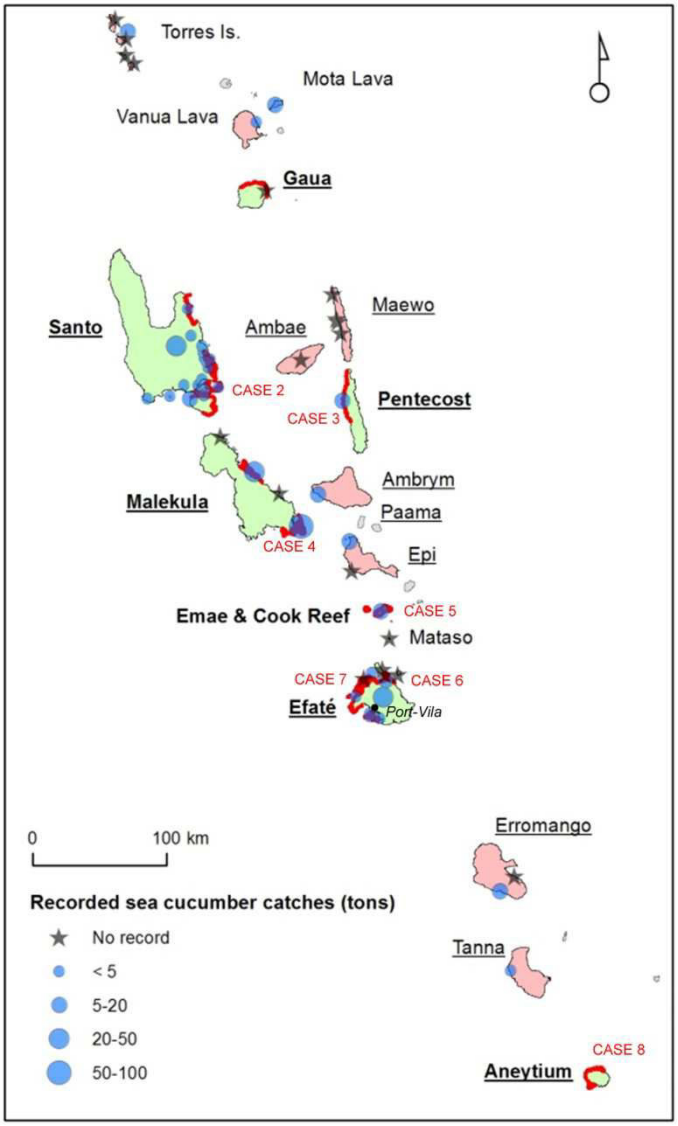

Figure 6. Harvest sites and respective recorded catches of sea cucumbers (all species together, wet weight) during the nationwide open season in 2015 (blue spots). The open season was officially declared in September 2015 in the seven islands of Vanuatu (in green, bold names) where assessment data was available (red areas). Harvest eventually occurred in many other islands (in pink, regular names). Documented harvest sites in which no catch data was collected by the fisheries department (no authorized observer present on site) are represented by stars. Species-specific TACs had been defined prior opening for most islands of the country (underlined names) by Fisheries Regulations Order No. 120 of 2015.

3.3.3.2 Catch records

The Fisheries Department engaged unprecedented human resources in sea cucumber catch monitoring during the open season since the sea cucumber fishery emerged as a priority issue. On-site catch monitoring involved seven permanent fishery officers of the extension and compliance divisions (four and three officers, respectively), as well as 15 contracted fishery observers. The catch monitoring procedure was coordinated by the research division based at Port-Vila. The same protocol as that of 2014 was used to collect catch data. Data entry onto the fisheries department's database was performed by three contracted (part-time) fishery officers from November 2015 to January 2016.

However the fisheries department was not able to monitor all fishing operations and to enforce TACs due to the high number of simultaneous fishing sites in the six provinces. Fishery officers and observers were only based at some processing sites where catches were aggregated, including sites of local case studies discussed in this paper. Overall 320 tons (wet weight) of sea cucumber catches were recorded during the open season (~37 % of all estimated catches). Recorded catches mainly came from Malekula (including case 4), Santo (case 2) and Efate (including case 6 and 7) islands. However, given that ~63 % of catches were not recorded on site, available records were likely not representative of the spatial distribution of sea cucumber catch across Vanuatu islands, particularly in the sites that were not included in the case studies. For instance, anecdotic or nil catch was recorded in some islands despite harvest undoubtedly having occurred in those areas (e.g., Gaua, Tanna, Maewo, Ambae islands, Figure 6). Islands with high biological potential were targeted as a priority and were more heavily fished than other areas.

In total 19 species were observed in catches. Four species represented 69% of total recorded catches (namely surf redfish (22%), tigerfish (21%), brown sandfish (14%), and greenfish (11%)) while eight species totaled only ~2% % of total recorded catches. However, these records are not fully representative of the sea cucumber catch composition. Catches of the main target species usually exceeded TACs by 100% to above 500% (e.g., surf redfish, tigerfish, brown sandfish, greenfish, black teatfish) particularly in Malekula (including case 4), Santo (case 2) and Efate islands (including case 6). Unauthorized species were also harvested due to their high value (e.g., white teatfish) or high abundance (snakefish) locally while several low value species were anecdotally collected regardless of allocated catch (e.g., chalkfish, elephant trunkfish).

3.3.3.3 Export records

Final beche-de-mer products were aggregated in Port-Vila and Luganville for export to Hong-Kong (97.7%) and Fiji (2.3%). Exports occurred from October 2015 to February 2016 although harvest stopped on December, 31st 2015 since sea cucumber processing was carried out after fishery closure. In total nine processing companies exported beche-de-mer in 2015 (seven companies) and/or in 2016 (seven companies), including those products that had been processed by other companies that did not hold export licenses. Two companies exported very

low quantities of bêche-de-mer (0.4 ton and 0.3 ton) while the remaining companies exported from 3.97 tons to 16.53 tons of bêche-de-mer.

As with catch monitoring, the fisheries department engaged unprecedented human resources in sea cucumber export monitoring during and after the open season. The seafood verification agency (three permanent officers) inspected all export packages with the assistance of compliance officers. Export companies were requested to pack bêche-de-mer products by species in 20-40 kg bags and to provide a packing list invoice for each bag (indicating species, total number of pieces and weight, destination and indicative sale price). However, harvest sites were not recorded since catches from different origins had been mixed prior to processing and/or packing.

Total beche-de-mer exports reached 18.6 tons in 2015 and 50.8 tons in 2016, for all species together (69.4 tons in total), which was close to the highest historical records (Figure 1). Total exports therefore highly exceeded the total TAC (21 tons) by 48.4 tons (234%). The corresponding catch was over 1 million sea cucumbers and 939 tons wet weight (Table 3). The species breakdown of bêche-de-mer exports was made available for the first time in 2015-2016. In total 21 species were observed in exports. Four species represented 68% of total recorded catches (namely surf redfish (30%), tigerfish (15%), brown sandfish (12%), and black teatfish (10%)) while seven species totalled ~0.9% of total exports (Table 3).

The species breakdown of exports showed that on-site catch records and export records of three main species (surf redfish, tigerfish and greenfish) were not consistent. These differences in catch composition highlight that significant harvest very likely occurred in reef areas and islands that had not been monitored by the fisheries officers in 2015.

For the first time, the fisheries department recorded the size distribution of bêche-de-mer exports of each species in 2015-2016. Importantly we observed that the exports of most species were mainly composed of undersized sea cucumbers. Specifically, the mode of the size distribution of the five main species (each species representing >5% of exports) was much lower than their respective minimum export sizes. As a result total exports of these species were composed of 82 % to 97 % undersized specimens, which is an abnormally high and unsustainable rate.

Although the high total exports recorded during the open season in 2015 may suggest healthy and abundant sea cucumber resources, such an interpretation would be misleading. Instead they resulted from intensive fishing and relatively low yields in a large number of villages' marine areas throughout the country during the 4-month open season, as highlighted by the size distribution and species composition of exports and the fishing strategy. This confirms that sea cucumber stocks were broadly low and had only partly recovered during the moratorium.

3.3.3.4Compliance issues

Fisheries department officers of the compliance division (including permanent officers and contracted fishery observers), the extension and development division and the seafood verification agency enforced Fisheries Regulations Order No. 120 of 2015 during fishing and processing of sea cucumbers and prior to export of dried products.

A total of 15 part-time fishery observers were contracted at the compliance division for the sea cucumber fishery during the open season. They were trained by the research division of the fisheries department concerning species identification and catch monitoring procedure. Functioning costs of fishery observers (i.e., US$20 per diem and travel costs) were covered by the processing companies as a condition of their license.

A processing license was charged for purchasing sea cucumbers and processing them to dried products (bêche-de-mer). An export license was charged for exporting processed products to overseas markets. The separation of processing license from export license was to ensure efficient monitoring of the activities of license holders and the enforcement of the TACs.

Fishery observers played a key role in the sea cucumber fishery during the open season as acknowledged by all processing companies and local communities. They i) provided awareness to communities (on minimum harvest sizes, species, prices, license conditions, etc.), ii) worked as facilitators between buyers and local communities, iii) worked as local coordinators of harvest operations, and iv) were responsible for monitoring sea cucumber catches and enforcing fisheries regulations. Fishery observers were assisted by WanSmolBag resource monitors in case studies 4, 5, 6, 7, and 8.

Despite the above management efforts of the fisheries department, major compliance issues emerged during the open season. Some specifications of Fisheries Regulations Order No. 120 of 2015 precluded the enforcement of the TACs despite monitoring activities:

- Contrary to the harvest strategy implemented in 2014, the processing license conditions did not set limits on the purchases of sea cucumbers by each licensed company. This weakened the fisheries department's capacity to stop fishing activities when the TACs of some species were reached;

- Catch-sharing between villages proved to be unmanageable once harvesting had started. Given that the TACs were set at the island level rather than at the community level as established in 2014, and that harvest simultaneously occurred in multiple fishing areas throughout Vanuatu, the fisheries department was not able to share the TACs among villages during the open season. This raised confusion and concern in the case studies 4, 5, and 6, as the communities in those sites were well aware of the TAC-based harvest system and therefore expected the fisheries officers or the fisheries observers to set and monitor TACs per species.

- Given that the species-specific TACs were set in dry weight rather than in wet weight as established in 2014, compliance with the TACs was only controllable at export gates once processing had fully been completed, i.e. one to two months after harvest (or more since dry products can be easily stored). Therefore the fisheries department was unable to use catch data to enforce the TACs at the time of fishing (except in case study 7). As a result 50.8

tons of bêche-de-mer were exported in 2016 although total exports on December, 31st 2015 were lower (18.6 tons) than the total export limit (Table 3). This markedly stressed that TACs should be set in wet weight to allow for controlling catch limits on time in harvest and/or processing sites.

Interestingly communities in the southwest coast of Efaté Island (case study 7) followed the fisheries department's initial harvest recommendations and did not overharvest their resources. Communities in Aneytium island (case study 8) did not allow processing companies to purchase sea cucumbers in their fishing areas, that remained un-fished.

Table 3. Total TAC, exports and catch in excess of quota (in kg of dried products) for each sea cucumber species in 2015 and 2016. Source of raw data: Fisheries department, seafood verification agency

Species	Total TACs (kg)	Exports (kg)			Catch in excess of quota (kg)
		2015	2016	Total	
Surf redfish	1 560	4 985	16 137	21 122	19 562
Tigerfish	1 040	3 445	7 075	10 520	9 480
Brown sandfish	600	2 468	5 761	8 229	7 629
Black teatfish	140	1 928	5 076	7 004	6 864
Greenfish	1 320	1 366	2 839	4 205	2 885
Snakefish	-	294	2 599	2 894	2 894
Prickly redfish	2 730	706	1 981	2 687	-
Lollyfish	2 400	1 045	1 360	2 405	-
Hairy blackfish	1 100	154	1 746	1 899	799
Chalkfish	1 080	957	865	1 822	742
White teatfish	540	205	1 578	1 782	1 242
Curryfish	680	516	1 019	1 535	855
Deepwater blackfish	-	57	1 366	1 423	1 423
Stonefish	3 000	86	1 185	1 271	-
Elephant trunkfish	3 380	88	146	235	-
Brown curryfish	160	100	0	100	-
Mixes species	-	84	0	84	84
Sandfish	-	72	0	72	72
Peanutfish	-	40	27	67	67
Flowerfish	-	19	8	27	27
Amberfish	1 300	0	27	27	-
ALL SPECIES	21 030	18 615	50 796	69 412	48 382

A total of six offences were reported in the sea cucumber fishery during the open season. Five companies breached one or two specifications of their processing license by operating without the presence of a fishery observer (n=4) and/or processing undersized sea cucumbers (n=2). Four spot fines were issues (US$500 or US$1500) and two processing licenses were temporarily or permanently suspended. The number of penalized offenses for processing undersized sea cucumber was much lower than expected given the high rate of reported undersized sea cucumbers in exports. Indeed the fisheries department usually provided awareness and issued warnings at inspections, which proved ineffective in discouraging the harvest, purchase, processing and export of undersized sea cucumbers. Overall size limits

were largely not enforced. Monitoring data showed that fishers harvested sea cucumbers opportunistically, whatever their size.

3.4 Phase 3 of the intervention (2016)

The distribution of economic returns from the sea cucumber fishery following harvesting in 2015 was analyzed among local communities, processing and export companies and the Vanuatu government.

The feedback from local communities concerning local economic returns was overall positive to very positive (i.e., "we made quick money"). Local economic returns included i) payment to fishers based on purchase prices, ii) royalties to communities and/or landowners (e.g., US$500 to US$1,000), and/or ii) a profit-sharing rate (e.g., 5 %) to local leaders (including chiefs and community council) depending on local arrangements with companies' agents.

As far as fishers were concerned, local economic returns reached ~ US$1,056,000 in 2015 as estimated by the total first sale value of sea cucumber catches. This represented 35.4% of the total export value of processed products. Given that several thousands of fishers were involved in the sea cucumber fishery in 2015, the individual revenue from sea cucumber sale was likely < US$200 for most fishers. Sea cucumbers were paid per piece rather than per kg. Purchase prices greatly differed among species and among buyers and averaged US$1 per piece (US$1.1 per kg). Disputes were reported by fishery observers and fishery officers concerning purchase prices that were judged unfair in some communities.

The feedback from processing and export companies concerning economic returns was overall positive to very positive ("we made good business, good money"). The total export value of sea cucumber catches reached their highest historical levels in 2015 (US$874,000) and in 2016 (US$2,110,000) (Figure 1). The most contributing species were surf redfish (38% of export value), black teatfish (17.4%), tigerfish (9.9%), greenfish (6.8%), brown sandfish (6.8%) and white teatfish (6.7%). However the feedback from Ni-Vanuatu license holders was mitigated due to perceptions of unfair benefit sharing and lack of transparency of foreign investors.

The fisheries department did not recover the management costs of the fishery despite the appropriate legal framework in place, which generated frustration among fisheries staff. The total tax revenue from the sea cucumber fishery to the Vanuatu government in 2015 and 2016 reached ~ US$220,000 (20.8% of total first sale value and 7.4% of total export value of beche-de-mer). This represented only ~50% of expected tax revenue. For instance the 5% export levy was not implemented and most breaches of minimum size limits were not penalized. The reasons for the large gap between expected and achieved tax revenue remain unclear although several conflicts of interest between private and political individual bodies may be hypothesized. Furthermore the processing and export fees had been set by the fisheries department according to a total TAC of 21 tons (dry weight) while exports eventually exceeded the total TAC by 48.4 tons (230%). The Fisheries Department did not collect additional fees for this surplus production that should have generated additional tax revenue in comings years.

Exceptionally high economic outputs (~US$3,000,000) were reached in 2015 and 2016 at the cost of severe market-driven resource depletion throughout the country. This squandered possible income from the sea cucumber fishery in the next 5-10 years.

Unsurprisingly the Vanuatu government therefore closed the sea cucumber fishery on January, 1st 2016 at national level following the national management plan (Table 2). Overall communities and industry supported that decision due to evidence of resource depletion in most fishing grounds. However communities that had not overharvested or even harvested sea cucumber resources in their marine tenure (e.g., in cases 7 and 8) expected the fishery to re-open under the same operating conditions that prevailed in 2014 in pilot co-management sites.

4 Scores of criteria of institutional performance

Based on the primary data acquired throughout the intervention in the nine case studies, eleven evaluation criteria of institutional performance were retained (see main text). The annual scores for each of the criteria are indicated in Table 4.

Table 4. Annual scores for each of criteria of institutional performance derived from institutional diagnosis of the case studies.

Case study	Year	Governance criteria										
		Outcome criteria				Instrumental criteria					Interactional criteria	
		Actors' behavior (3 scores)	Resource biomass (3 scores)	Trend in biomass (3 scores)	Relative catches (3 scores)	Enforcement (4 scores)	Government support (3 scores)	Individual learning (3 scores)	Capacity for action (4 scores)	Organization (3 scores)	Actors' strategies (3 scores)	Collective learning (3 scores)
1	2008	2	2	2	2	3	2	1	2	2	3	2
New Caledonia	2009	3	3	3	2	3	2	3	4	3	3	3
(Northern	2010	3	3	3	2	3	2	3	4	3	3	3
province)	2011	2	3	3	3	1	2	3	3	3	3	3
	2012	2	3	3	3	1	2	3	3	3	2	2
	2013	2	3	3	3	1	2	3	2	3	2	2
	2014	3	3	3	3	1	3	3	3	3	2	3
	2015	3	2	1	2	4	3	3	3	3	2	3
	2016	3	3	3	2	4	3	3	3	3	2	3
2	2010	1	1	2	1	2	1	1	1	1	1	1
Vanuatu	2011	1	1	2	1	2	1	1	1	1	1	1
(Santo island)	2012	1	1	2	1	2	1	1	2	1	1	1
	2013	1	1	3	1	2	1	1	2	1	1	1
	2014	3	1	3	2	2	1	1	4	1	2	1
	2015	1	1	1	3	1	1	1	2	1	2	1
	2016	1	1	1	1	2	1	1	2	1	1	1
3	2012	2	2	2	1	2	1	1	1	2	1	1
Vanuatu	2013	2	2	3	1	2	1	1	2	2	1	1
(Pentecost island)	2014	3	2	3	2	2	1	2	4	2	3	2
	2015	1	2	2	3	1	1	1	2	2	2	1
	2016	1	2	2	1	2	1	1	2	2	1	1
4	2010	1	2	2	1	2	1	1	1	2	1	2
Vanuatu	2011	1	2	2	1	2	1	2	2	2	1	3
(Malekula island)	2012	2	3	2	1	2	1	2	2	2	1	2
	2013	2	3	3	1	2	1	2	2	2	1	2
	2014	3	3	3	2	4	3	3	4	2	3	3
	2015	2	1	1	3	1	3	2	3	2	2	2
	2016	2	1	1	1	2	1	2	3	2	1	2
5	2012	1	3	2	1	2	1	1	1	2	1	2
Vanuatu	2013	2	3	3	1	2	1	1	1	2	1	2
(Emae island)	2014	3	3	3	1	2	1	3	4	2	3	3
	2015	2	2	1	3	1	3	3	3	2	2	3
	2016	2	2	1	1	2	1	3	3	2	1	2
6	2010	1	1	2	1	2	1	1	1	1	1	1
Vanuatu	2011	1	1	2	1	2	1	1	2	1	1	2
(Efate island	2012	2	1	2	1	2	1	1	2	1	1	2
- north)	2013	2	1	3	1	2	1	1	2	2	1	2
	2014	3	1	3	2	4	3	3	4	2	2	3
	2015	2	1	2	3	1	3	2	3	1	2	2
	2016	2	1	2	1	2	1	2	3	1	1	1
7	2012	2	1	2	1	2	1	1	1	2	1	3
Vanuatu	2013	2	1	3	1	2	1	3	4	2	3	3
(Efate island	2014	3	1	3	3	4	3	3	4	2	3	3
- southwest)	2015	3	1	3	3	4	3	3	4	2	3	3
	2016	3	1	3	1	4	1	3	4	2	3	3
8	2012	2	2	2	1	2	1	1	1	2	1	2
Vanuatu	2013	2	2	3	1	2	1	3	4	2	3	3
(Aneityium island)	2014	2	2	3	1	2	1	3	4	2	3	3
	2015	3	2	3	1	3	3	3	4	2	3	3
	2016	3	2	3	1	4	1	3	4	2	3	3
9	2010	1	2	2	1	2	1	1	1	1	1	1
Vanuatu	2011	1	2	2	1	2	1	1	2	1	1	2
(national)	2012	2	2	2	1	2	1	1	2	2	1	2
	2013	2	2	3	1	2	1	1	3	2	2	2
	2014	3	2	3	2	4	3	2	4	2	2	3
	2015	2	1	1	3	1	3	2	2	2	2	2
	2016	2	1	1	1	2	1	2	3	2	3	2

Conclusion de la Partie 2

1) Notre démarche de recherche-action dans neuf cas d'étude du Pacifique sud a permis d'examiner empiriquement les conditions de développement d'institutions de cogestion par des interventions publiques dans des petites pêcheries. Les effets de notre expérimentation adaptative et multi-échelle sur la dynamique de la gouvernance de petites pêcheries d'holothuries ont été évalués par un cadre d'analyse multidimensionnel en fonction des contingences internes et externes, conformément au modèle causal théorique posé en introduction. Les résultats mettent en évidence que l'expérimentation adaptative est une voie prometteuse à la fois pour comprendre les dynamiques de coopération et pour contribuer à rendre durables des régimes de cogestion des petites pêcheries. Ces résultats sont discutés plus avant ci-dessous.

2) L'un des résultats les plus marquants est la similitude des changements diagnostiqués du profil de gouvernance entre les cas au cours des trois à cinq premières années de l'intervention. Un support documentaire a été réalisé pour faciliter le transfert de cette expérience entre les cas d'étude (https://nouvelle-caledonie.ird.fr/science-en-partage/videos-canal-ird/dans-un-esprit-de-cogestion). Pendant cette période de construction institutionnelle, l'intervention a agi sur de nombreux médiateurs et résultats. La recherche-action a permis d'identifier empiriquement les facteurs-clés du processus de coopération et de création institutionnelle, et leurs interactions. Les facteurs-clés instrumentaux étaient les suivants : (i) connaissance individuelle du fonctionnement dynamique du système halieutique et des bénéfices de la mise en œuvre des institutions ; (ii) développement des capacités techniques (bases de données, méthode d'évaluation statistique appropriées, maîtrise des outils informatiques) et d'action (suivis participatifs biologiques et halieutiques, moyens financiers appropriés) des acteurs locaux et publics ; (iii) définition conjointe des institutions par les acteurs locaux et privés et les autorités publiques qui les soutiennent par des réglementations officielles ; (iv) capacités de faire respecter les règles par autocontrôle des pêcheurs et/ou par les autorités publiques ; et (v) développement d'une organisation permettant des discussions et des décisions collectives au niveau local et des administrations. Les facteurs-clés interactionnels étaient les suivants : (vi) consensus tacite sur une stratégie collective à adopter, dû au soutien par l'intervention des autorités publiques et aux perceptions locales partagées sur la faiblesse des ressources relativement au niveau des années précédentes ; et (vii) apprentissage collectif grâce aux actions collaboratives et aux échanges réguliers de suivi du système, qui ont développé les relations de confiance et des responsabilités partagées. Enfin (viii) les résultats mesurés (changement comportemental, évolution de la densité de biomasse des ressources à haute valeur commerciale, captures relatives), positifs dans chaque cas, ont permis de renforcer les facteurs précédents.

3) La performance institutionnelle globale des systèmes halieutiques a ainsi été augmentée à court terme dans chaque cas d'étude. Spécifiquement, ce résultat montre que la recherche-action est une approche holistique qui peut contribuer efficacement à améliorer en pratique la performance de la gouvernance des petites pêcheries en trois à cinq années, alors que celles-ci

étaient régulièrement surexploitées auparavant. Couplée au développement d'un cadre d'évaluation des impacts des interventions, la recherche-action, s'est avérée être également une approche expérimentale pertinente pour analyser la dynamique du changement institutionnel dans les petites pêcheries.

4) Les valeurs des critères de gouvernance impactés positivement par l'intervention n'ont pas augmenté dans un ordre prédéterminé. L'évolution de la performance de la gouvernance a suivi des trajectoires temporelles spécifiques suivant les cas. La structure et la dynamique de la construction institutionnelle ont été adaptées au contexte de manière opportuniste, en profitant des fenêtres d'opportunités et en répondant aux inévitables changements imprévus (e.g., Blyhte et al. 2017). Ces trajectoires des profils de gouvernance des cas d'étude ont été suivies sur une période suffisamment longue pour analyser opportunément la réponse des institutions à des stress multiples. Ceux-ci ont parfois dépassé les capacités de gouvernance du système, comme documenté dans d'autres pêcheries d'holothuries (Kaplan-Hallam et al. 2017).

5) Spécifiquement, la méthode d'analyse des trajectoires temporelles s'est montrée pertinente pour étudier la durabilité des institutions. Celle-ci a été évaluée à travers les capacités d'adaptation et de résilience de la gouvernance dans les cas d'étude. Nous avons constaté que malgré des effets positifs à court terme, les interventions n'avaient pas systématiquement permis de constituer des capacités de cogestion suffisamment robustes pour supporter et/ou s'adapter aux effets combinés et/ou interactifs de quatre principaux types de perturbations le plus souvent imprévisibles :

i) l'intervention de recherche-action elle-même, visant à développer un mode de cogestion des pêcheries, a transformé les interactions existantes de l'arène sociale ;

ii) l'augmentation des ressources à haute valeur commerciale, suite à l'intervention, a eu des effets interactifs et cumulatifs indésirables et imprévus sur le processus de construction institutionnel dans un contexte d'économie mondialisée. D'une part en apportant une solution au problème de surexploitation, la situation de crise des pêcheries qui avait justifié l'expérimentation a par définition été temporairement résolue, ce qui a entrainé des stratégies individuelles divergentes. D'autre part l'augmentation consécutive des rendements de pêche individuels s'est répercutée sur les coûts d'opportunité des institutions et les bénéfices attendus du non respect de ces institutions. Ces effets pourraient être appelés « le prix du succès » et ont encouragé une surexploitation des ressources d'holothuries ;

iii) une crise environnementale et socioéconomique imprévisible et à grande échelle a entraîné au Vanuatu un intérêt exceptionnel des communautés littorales pour la pêcherie d'holothuries. Cet événement a constitué une contingence externe brusque et très forte ;

iv) des changements administratifs à la direction du service des pêches ont diminué les capacités de gouvernance au Vanuatu et en Nouvelle-Calédonie. Quatre facteurs interactifs étaient en cause : retrait (par changement de poste administratif) d'un acteur-clé, implication dans le dispositif de gouvernance gouvernementale d'un nouvel acteur-clé qui n'avait pas

participé au processus d'apprentissage, désorganisation des capacités d'action du service des pêches, et inefficacité des moyens de contrôle des restrictions de pêche mises en place.

Les impacts de ces perturbations sur le processus institutionnel ont été différents suivant les cas, en fonction des capacités de résilience plus ou moins élevées que l'intervention avaient développées.

6) Enfin, le développement institutionnel dans le cas d'étude national n'a pas évolué comme une juxtaposition de cas locaux. Les différences indiquent que des facteurs différents opèrent en fonction de l'échelle du système halieutique considérée, et que la performance institutionnelle à un niveau supérieur ne dérive pas directement de celle des niveaux inférieurs.

CONCLUSION GENERALE

Dans ce travail, nous avons étudié les modes de gestion et de gouvernance de deux des principales catégories de pêcheries récifales du Pacifique sud insulaire : d'une part les pêcheries de poissons récifaux, alimentant le marché et la consommation au niveau local et national (chapitres 1.1 et 1.2), et d'autre part les pêcheries d'holothuries, alimentant le marché d'exportation (chapitres 1.1, 2.1 et 2.2). L'étude a porté sur différentes échelles spatiales et sociopolitiques, en considérant les territoires maritimes intra-communautaires (chapitres 1.1 et 1.2), les connections horizontales inter-communautés (chapitres 1.2, 2.1 et 2.2), et les connections verticales entre les communautés locales et les administrations provinciales ou gouvernementales (chapitres 1.1, 2.1 et 2.2). Elle a également porté sur la temporalité des modes de gestion et de gouvernance des pêcheries récifales en considérant principalement leur dynamique interannuelle (chapitres 1.1, 2.1 et 2.2) et intra-annuelle (chapitres 1.2 et 2.1). Enfin, les cas des pêcheries étudiés en Nouvelle-Calédonie et au Vanuatu comportaient des contextes environnemental, socioéconomique, administratif et politique variables, même s'ils s'intégraient dans la même région socioculturelle de la Mélanésie, comme présenté en introduction.

4.1 Opportunités et contraintes d'une gestion multi-échelle des petites pêcheries du Pacifique sud

4.1.1 Une gestion spatialisée, multi-échelle, par cycles d'exploitation

Bien que nos cas d'étude ne représentent qu'une partie de la diversité des conditions rencontrées en Océanie, les résultats ont montré que la gestion spatialisée et multi-échelle des pêcheries récifales par des cycles de fermetures et d'ouvertures temporaires de la pêche constitue une forme concrète d'hybridation de la gestion communautaire et gouvernementale adaptée à de nombreuses pêcheries mono- ou plurispécifiques du Pacifique. Il s'agit d'une stratégie de gestion socialement acceptée et permettant d'opérationnaliser les politiques des pêches qui promeuvent des formes de cogestion des petites pêcheries (Ruddle 1998), ce qui favorise sa persistance sur le long terme. En particulier, elle permet de concilier les perceptions hétérogènes à l'intérieur des communautés, influencées par les relations de pouvoir, les conflits sur la propriété foncière maritime, les droits d'accès et la distribution des bénéfices attendus lors de l'ouverture de la pêche (Cohen et Steenbergen 2015). Nos résultats généralisent ainsi les recherches antérieures qui encouragent les mécanismes de coopération

entre l'administration des pêches et les populations villageoises à l'échelle de la tenure maritime communautaire (e.g., Johannes 1998a, 1998b, 2002 ; Aswani 2005).

Cette stratégie collective de gestion par cycles, comparable à des épisodes successifs de mise en jachère halieutique ou de moratoire, peut être plus facilement mise en œuvre que la plupart des institutions de gestion des ressources communes (Ostrom 1990). Plus précisément, son efficacité a été analysée selon deux modalités, comme explicité ci-dessous.

4.1.2 Contrôler l'exploitation pendant les ouvertures périodiques de la pêche

La stratégie de gestion multi-échelle par cycles a été analysée respectivement sans (Partie 1) et avec (Partie 2) limitation des captures à l'ouverture de la pêche. Dans le cas où les captures n'étaient ni contrôlées ni limitées à l'ouverture des zones à la pêche, nos résultats ont montré que l'accumulation temporaire des ressources pendant la période de fermeture était prélevée et même dépassée en un temps court à très court, en raison de l'accroissement de l'attractivité de la pêcherie pendant la période de fermeture, ce qui confirme les résultats d'autres travaux (e.g., Jupiter et al. 2012 ; Cohen et Alexander 2013). Cette durée dépend à la fois de l'accroissement de la biomasse exploitable pendant la fermeture et des capacités de pêche qui peuvent être déployées par les villages à l'ouverture. A l'échelle communautaire, cette durée était de l'ordre de quelques jours seulement dans les réserves marines temporaires ciblant les poissons récifaux et dans les pêcheries d'holothuries. A l'échelle nationale au Vanuatu, cette durée était de l'ordre de quatre mois dans le cas des pêcheries d'holothuries, qui représentent certainement un cas extrême compte tenu de la demande mondiale exacerbée sur ces espèces (cf. Partie 2). En d'autres termes, les droits territoriaux communautaires d'accès aux pêcheries, bien que limitant l'exploitation aux seuls pêcheurs des communautés, sont nettement insuffisants pour restreindre l'effort de pêche effectif à un niveau soutenable, malgré l'enthousiasme généré par l'approche communautaire des réserves marines et plus largement de la gestion des pêcheries récifales (Johannes 2002 ; Bartlett et al. 2009 ; Benbow et al. 2014).

Des restrictions spécifiques supplémentaires sont donc requises pour limiter l'effort de pêche à l'ouverture. Il est intéressant de noter que la stratégie de gestion spatialisée des pêcheries récifales par cycles d'exploitation est alors conforme aux préconisations théoriques sur la régénération des ressources : des cycles successifs de fermetures et d'ouvertures temporaires constituent en effet la dynamique de régénération la plus rapide, à condition d'ajuster l'effort de pêche et/ou les captures et de fermer la pêche avant l'effondrement des ressources pour assurer la durabilité des pêcheries (Dasgupta 1982). Cette solution peut donc fonctionner selon une logique adaptative uniquement si un suivi *a minima* des captures et de l'effort est effectué pendant les périodes d'ouverture successives pour évaluer l'effet de la pêche sur les ressources (e.g., captures par unité d'effort, structure en taille des espèces cibles) *et* permettre

un ajustement de l'effort autorisé pendant plusieurs années, comme illustré dans la Partie 2 de ce travail. Les suivis biologiques nécessitent quant à eux des capacités financières et techniques plus élevées, et dépendent par ailleurs de contingences écologiques sur les ressources (e.g., sédentarité), ce qui limite en pratique leur application aux ressources d'invertébrés benthiques (Perry et al. 1999).

Deux options ont été mises en œuvre avec succès dans les cas d'étude : la limitation drastique de l'effort de pêche effectif (e.g., nombre de pêcheurs.jours) et/ou la limitation du total admissible des captures (TAC collectif ou individuel). En l'absence de données biologiques sur l'état des ressources, trois communautés de nos cas d'étude au Vanuatu ont empiriquement restreint de manière préventive l'effort de pêche à un jour de pêche par an dans leurs réserves marines, ou à certaines espèces de petits pélagiques, suivant une approche de précaution. Dans les cas où un suivi biologique a été développé, dans les pêcheries d'holothuries, des TAC collectifs et/ou individuels non transférables ont pu être mis en œuvre, et se sont révélés performants sur le plan biologique lorsqu'ils étaient effectivement respectés.

Le coût du suivi nécessaire de l'activité de pêche pendant les périodes d'ouverture et de ses effets sur les ressources devant être relativisé par rapport à la valeur des pêcheries elles-mêmes, il s'ensuit que le suivi des pêcheries à haute valeur commerciale et les méthodes de suivi participatives doivent être envisagés en priorité, comme illustré dans ce travail (Partie 2).

4.1.3 Augmenter l'échelle de gestion

L'existence de droits de pêche territoriaux dans les communautés du Pacifique restreint *de facto* l'échelle socio-spatiale de mise en œuvre de la gestion communautaire à des zones de petites dimensions (typiquement inférieures à 10-20 km^2), ce qui constitue une limite intrinsèque de l'efficacité potentielle de ce mode de gestion (Foale et Manele 2004). Afin d'augmenter les impacts de telles mesures de gestion localisées, une approche multi-échelle a été explorée dans ce travail selon deux directions.

D'une part la mise en réseau de réserves marines communautaires est apparue comme une perspective de gestion innovante (chapitres 1.1 et 1.2), promue par ailleurs dans des systèmes de plus grandes dimensions (Gaines et al. 2010). Bien que les communautés villageoises aient peu de flexibilité sur la localisation et l'étendue des zones susceptibles d'être mises en réserve, en raison des contraintes de surveillance et d'acceptabilité sociale, la coopération inter-villages pourrait permettre d'optimiser ces paramètres et l'espacement entre les réserves. Ce changement d'échelle offrirait une meilleure protection à un plus grand nombre d'espèces exploitées et permettrait d'améliorer les effets des réserves sur les pêcheries récifales multi-spécifiques (Sale et al. 2005). Il vise à définir un meilleur compromis entre l'accumulation de biomasse dans les réserves marines et les bénéfices halieutiques directs (lors de l'ouverture

des réserves) et indirects (par la capture de poissons se déplaçant hors des limites des réserves), et ainsi à améliorer l'efficacité écologique des réserves en tant qu'outil de gestion des pêcheries récifales multi-spécifiques. Plus largement, la complémentarité des règles de gestion communautaire entre villages voisins selon une approche horizontale de la gouvernance permettrait une augmentation de l'échelle de gestion et une meilleure adéquation des mesures de gestion à l'écologie des ressources, en raison de la connectivité des populations exploitées entre les territoires maritimes au stade adulte.

D'autre part, une approche verticale de la gouvernance a été expérimentée sous la forme de stratégies d'exploitation locale soutenues par les administrations des pêches. La formalisation du soutien des autorités publiques à l'élaboration et à la mise en œuvre collectives des institutions a notamment eu des effets significatifs positifs sur la performance du processus de construction institutionnelle (chapitre 2.2). Elle a reconnu et développé le rôle essentiel de ces autorités dans la construction du processus de cogestion avec les communautés locales et les autres acteurs économiques et politiques (Pomeroy et Viswanathan 2003 ; Beddington et al. 2007). L'engagement des autorités publiques a ouvert la voie à des interventions légitimes promouvant la cogestion des pêcheries dans de nombreuses localités. Les deux perspectives d'élargissement de l'échelle de gestion peuvent alors été conciliées, comme illustré dans le cadre de notre expérimentation sur les pêcheries d'holothuries au Vanuatu, où les villages voisins ont notamment interagi pour diviser les TACs collectifs respectifs, définir les périodes de pêche, et négocier les prix d'achat des captures (chapitre 2.2).

Dans notre étude, les modalités de la gestion multi-échelles par une mosaïque de zones gérées localement et/ou des interactions verticales entre les niveaux de gouvernance étaient spécifiques au contexte des pêcheries. Elles font l'objet de la section suivante.

4.2 Les processus du développement institutionnel dans la gouvernance des petites pêcheries

4.2.1 Le paradoxe des régimes de cogestion des petites pêcheries

Mise en avant dès 1984 lors de la première conférence des pêches pour accompagner les programmes d'aménagement (FAO 1984), la participation des pêcheurs dans la gouvernance des pêcheries progresse lentement à l'échelle mondiale. Trente-deux ans plus tard, les directives volontaires visant à assurer la durabilité de la pêche artisanale dans le contexte de la sécurité alimentaire et de l'éradication de la pauvreté rappellent spécifiquement aux Etats et aux différents acteurs leurs rôles conjoints dans le développement d'approches participatives, notamment de cogestion (FAO 2015). Pendant cette période, la cogestion des petites

pêcheries est en effet clairement apparue comme la voie à suivre. Elle est communément reconnue au niveau mondial comme le régime de gouvernance le plus équitable, adaptatif et rationnel pour répondre aux enjeux de surexploitation des petites pêcheries (Sen et Nielsen 1996; Jentoft 2003; Wilson 2003 ; Folke et al. 2005; Mahon et al. 2005; Guttiérez et al. 2011; Seijo et Salas 2014). Le paradoxe est que les modes de cogestion restent minoritaires aujourd'hui dans les petites pêcheries malgré leurs impacts positifs largement démontrés dans de nombreux cas concrets.

Pour comprendre ce paradoxe, notre travail empirique a suivi une approche d'économie institutionnelle. Sur le plan économique, les régimes de cogestion sont plus efficaces que les régimes de gestion centralisés ou locaux car ils renforcent la légitimité multi-niveau des décisions (Baland et Platteau 1996; Jentoft 2000), et agissent donc positivement sur les incitations individuelles à coopérer et les coûts de transactions (Hanna 2003). Il est notamment attendu que les coûts de transaction élevés préalables à la mise en place de tout régime de cogestion soient compensés par de plus faibles coûts de transaction après cette phase de développement. Nous avons considéré que cet objectif de performance économique a été atteint lorsque les capacités d'adaptation et de résilience des systèmes face à des stress multiples ont été suffisamment développées pour rendre pérennes les changements institutionnels après la fin des moyens alloués pendant les interventions extérieures. En ce sens, l'analyse du processus de développement institutionnel et des effets de nos interventions (cf. Partie 2) a montré que l'objectif de performance économique des régimes de cogestion a été atteint lorsque l'intervention a obtenu des impacts positifs sur quatre processus institutionnels simultanément *et* pendant une à deux années consécutives. Ces processus-clés sont explicités ci-dessous.

4.2.2 L'apprentissage des interactions ressources-pêche : un pré-requis insuffisant

Nos interventions étaient motivées par un problème d'ajustement de l'effort de pêche et des captures en fonction du renouvellement biologique des ressources d'holothuries, afin d'assurer la durabilité de l'exploitation. Logiquement, l'apprentissage individuel des processus systémiques à l'œuvre (e.g., interactions entre les ressources et les conditions d'exploitation, problèmes de durabilité, effets potentiels du changement institutionnel) par les acteurs clés (y compris les acteurs non scientifiques hors des administrations des pêches), était l'un des principaux processus à prendre en compte pour définir et appliquer des institutions adaptées au contexte, effectives et coopératives selon une approche de cogestion adaptative. L'intervention devait ainsi améliorer l'apprentissage individuel, d'une part grâce à une meilleure compréhension individuelle du fonctionnement des pêcheries, et d'autre part grâce à une meilleure circulation et transparence de l'information.

Le choix des indicateurs biologiques et socioéconomiques et de leurs valeurs de référence était fondamental dans le processus de cogestion pour rendre ses impacts observables par les acteurs (cf. chapitre 2.1). Les points de référence dans la gestion des pêcheries, comme le rendement maximal durable, sont généralement basés sur des paramètres biologiques et halieutiques (e.g., mortalité par pêche, mortalité naturelle) qui ne peuvent pas être facilement calibrés dans les conditions spécifiques de nombreuses petites pêcheries d'invertébrés dont les holothuries (Seijo et Caddy 2000; Purcell 2010). Nous avons donc adopté une méthodologie d'estimation par inférence statistique d'un indicateur biologique simple à appréhender par les pêcheurs (i.e., la biomasse des espèces d'holothuries), facile à estimer par les administrations des pêches, sans hypothèse sur la biologie des espèces. Il est intéressant de noter que le niveau absolu de biomasse des ressources et des captures n'étaient pas systématiquement jugés les plus pertinents pour évaluer si l'objectif de l'intervention était atteint, bien qu'ils aient été mesurés et discutés pendant l'intervention. Au contraire, l'effet des mesures de gestion a été systématiquement interprété à partir de l'augmentation de la biomasse des espèces commerciales par rapport à leur niveau au début de l'intervention, c'est-à-dire au moment de l'engagement collectif dans la recherche-action. Cette tendance représentait une incitation biologique au développement institutionnel.

Ce résultat témoignait de la compréhension par les acteurs du caractère épuisable des ressources et de la nécessité de les régénérer, suite à la période de forte surexploitation ayant prévalu avant les interventions. Il rappelle en outre que le choix des indicateurs et des points de référence soulève des questions multiples qui renvoient à la production, à l'incertitude, à la communication et l'utilisation des savoirs sur les pêcheries, et qui déterminent finalement l'organisation des relations entre scientifiques, pêcheurs et autres acteurs administratifs et politiques de la gestion des pêcheries (Degnbol 2005). Depuis les années 1990, les suivis participatifs des ressources naturelles apparaissent de plus en plus comme une alternative aux suivis scientifiques réalisés sans réelle collaboration avec les acteurs. Ils sont en effet efficaces sur le plan financier tout en favorisant l'apprentissage individuel des acteurs et leur engagement dans le processus de décision et dans la gestion effective des ressources (Olsson et al. 2004 ; Danielsen et al. 2005). Comme illustré dans notre recherche, les suivis participatifs accompagnent utilement la démarche expérimentale de cogestion, participant ainsi à la mise en œuvre de boucles simples d'apprentissage (cf. introduction générale). Ils permettent notamment de mettre en discussion et de prendre en compte l'incertitude inhérente à la dynamique des ressources et aux estimations des indicateurs (Caddy et Mahon 1995 ; Charles 2001) : rendre cette incertitude explicite et transparente a permis d'améliorer les méthodes d'évaluation (e.g., taille des échantillons) et de définir des mesures précautionneuses de régulation de l'exploitation (chapitre 2.1). La volonté des acteurs de participer dans des programmes de suivi des ressources halieutiques dépend cependant d'une combinaison de conditions, dont la valeur économique des captures, le taux d'actualisation de leur valeur, la vulnérabilité des ressources à la surexploitation, leur importance socioculturelle, et les capacités techniques locales (Hockley et al. 2005). La qualité des

données collectées dans les suivis participatifs doit également être évaluée spécifiquement pour limiter les biais et la variabilité statistiques des estimations (Léopold et al. 2009).

De manière inattendue, la connaissance technique précise des mesures de gestion appropriées pour régénérer les ressources et les captures, qui constitue l'une des finalités majeures de la recherche halieutique, s'est cependant montrée insuffisante pour assurer la durabilité des pêcheries. Ce constat empirique était d'autant plus inattendu que les effets très positifs de ces mesures avaient été observés et reconnus par tous les acteurs clés, ce qui leur permettait de planifier l'exploitation et les bénéfices à venir. L'apprentissage individuel du fonctionnement des institutions et de leurs effets biologiques et économiques sur les pêcheries s'est ainsi révélé insuffisant pour développer la résilience des régimes de cogestion dans nos cas d'étude. En d'autres termes, ce résultat suggère que les modes de cogestion dont la légitimité repose seulement sur la démonstration de leur efficacité biologique et économique sont fragilisés. Le suivi des interactions dynamiques de gouvernance pendant la recherche-action a permis de mettre en évidence trois processus supplémentaires qui soulignent la nature stratégique de l'action et du changement institutionnel dans nos cas d'étude.

4.2.3 Trois autres processus du développement institutionnel à considérer

Homogénéisation des stratégies des acteurs

L'homogénéisation des stratégies des acteurs de nos cas d'étude était un processus inhérent à notre démarche de recherche-action. Ce processus reposait sur i) l'identification d'un objectif commun préalable (i.e., la régénération des ressources d'holothuries pour assurer une pêcherie durable), ii) la mise en œuvre d'actions collectives (i.e., suivi participatif des ressources et des captures) et d'institutions (i.e., TAC, quotas collectifs et individuels) acceptables par les différentes catégories d'acteurs cibles d'un point de vue économique, social et politique, et iii) le suivi quantitatif de l'effet des mesures de gestion sur la biomasse des espèces commerciales par rapport à leur niveau au début de l'intervention. Le bénéfice social net attendu d'actions collectives est en effet l'un des principaux facteurs qui orientent les intérêts et les décisions des acteurs, en fonction de leurs capacités de pouvoir respectives et des normes sociales (Poteete et al. 2009). Les stratégies des acteurs résultent notamment de ce compromis et affectent le développement de logiques coopératives, le changement institutionnel, et plus globalement la gouvernance des pêcheries. Dans tous nos cas d'étude, la faible dépendance des communautés vis-à-vis des pêcheries (poisson et d'holothuries) en début d'intervention a globalement facilité l'initiation de la démarche d'expérimentation : l'existence d'alternatives socioéconomiques diminuait le risque économique des usagers à s'engager dans l'innovation institutionnelle malgré les incertitudes inhérentes à la démarche expérimentale ; et la situation

évidente de surexploitation a entraîné un consensus pour mettre en œuvre une gestion collective active, de manière à reconstituer les stocks.

Nos recherches ont montré que la diversité des stratégies individuelles dans les contextes locaux limitait la nature des institutions acceptables et durables (chapitres 1.1 et 2.1), et pouvait s'exprimer sous la forme de conflits sociaux opposant des acteurs ou groupes d'acteurs aux intérêts divergents, et qui compromettaient parfois la survie des institutions (chapitre 2.2). Bien que ces acteurs ou groupes puissent être minoritaires en nombre dans le système considéré et s'opposer à l'intérêt commun, leur influence dans les relations de pouvoir était déterminante. Ce résultat souligne le rôle des coalitions, ou groupes stratégiques, qui réunissent des acteurs qui adoptent une stratégie collective conforme à leurs propres intérêts et influencent en conséquence la gouvernance des pêcheries (Agrawal 2008). La mise en cohérence progressive des stratégies respectives des acteurs-clés du système est ainsi apparue comme un processus déterminant de la performance économique des régimes de cogestion.

La difficulté rencontrée est venue de l'évolution des stratégies individuelles dans la plupart des cas d'étude pendant la recherche-action. Des changements de nature administrative, climatique et/ou économique, le plus souvent imprévisibles, y ont généré des effets interactifs et cumulatifs négatifs (chapitre 2.2). Ces changements sont intervenus selon différentes temporalités, progressivement ou brutalement, à l'échelle de quelques mois à trois ans. En augmentant la valeur actuelle des bénéfices économiques escomptés et/ou les coûts d'opportunité de la mise en œuvre des institutions collectives, ils ont notamment affecté les stratégies individuelles à court terme de certains usagers des ressources, en augmentant significativement leur motivation à créer des coalitions s'opposant à la stratégie collective élaborée (Mannix 1991). L'actualisation individuelle est en effet un processus intellectuel dynamique et complexe, qui intègre des facteurs psychologiques et des considérations sur les opportunités commerciales, la disponibilité des ressources et les relations de pouvoir (Price 1993). Elle témoigne du caractère intrinsèquement incertain du développement institutionnel dans les systèmes halieutiques.

Le constat d'un changement marqué des stratégies individuelles dans la plupart des cas d'étude entre deux à cinq ans après le début de l'intervention confirme d'une part que les relations conflictuelles entre les acteurs des petites pêcheries (en particulier entre les administrations publiques et les usagers) font partie intégrante des processus de cogestion et sont en pratique très probables (Singleton 2000). Il suggère d'autre part que ce phénomène est prévisible à court terme dans les régimes de cogestion, ce qui implique alors certaines recommandations de gestion dont il faudrait étudier les conséquences en matière de durabilité écologique, économique et sociale des pêcheries suivant les contextes considérés. Par exemple, la limitation volontaire des bénéfices globaux attendus des petites pêcheries commerciales par un choix d'objectifs de résultats sub-optimaux pourrait permettre de limiter l'attractivité économique de ces pêcheries, et donc les effets déstabilisateurs du marché sur la gouvernance tels qu'observés pendant notre recherche.

Apprentissage collectif

Afin de tenter d'homogénéiser les stratégies individuelles des acteurs sur le temps court, les interventions ont également développé l'apprentissage collectif dans les cas d'étude. Spécifiquement, la recherche-action a développé des interactions sociales régulières horizontales et verticales entre les acteurs d'un même système halieutique et entre plusieurs systèmes, compte tenu de leurs enjeux de gestion similaires. Le caractère adaptatif des expérimentations de cogestion (chapitres 2.1 et 2.2) a favorisé les boucles doubles d'apprentissage collectif par l'action (Fazey et al. 2005). Ces pratiques de cogestion, et leurs effets biologiques positifs, étaient nécessaires pour faire émerger une vision partagée des enjeux, des objectifs, et des moyens à mettre en œuvre pour les atteindre, renforçant ainsi les capacités d'apprentissage collectif (Carlsson et Berkes 2005; Armitage et al. 2008). Elles ont modifié les comportements des acteurs-clés, lesquels ont redéfini leurs actions respectives, leur rôle dans le système halieutique et donc la gouvernance de la pêcherie à l'échelle du système.

L'existence d'un changement de comportement des acteurs des pêcheries et de la gouvernance (e.g., agents des administrations des pêches) constitue logiquement une condition attendue pour observer un impact (positif) de l'intervention sur le système halieutique, et traduit la manière dont sont traités les dilemmes sociaux de coopération pendant l'intervention (Young 2008a). Il est utile de noter que ce changement de comportement concerne aussi les acteurs scientifiques et la renégociation de leurs rôles spécifiques dans le processus de gouvernance (Jentoft 2003). En particulier ce changement repose sur le partage d'une expérience commune entre les acteurs implantés dans le cas d'étude, ce qui nécessite la présence physique des acteurs scientifiques sur le terrain d'étude. Ce rapprochement pratique des scientifiques avec les réalités sociale et écologique des systèmes halieutiques (en particulier dans notre démarche de type expérimental) est de nature à renforcer leur implication effective dans le processus de gouvernance (Whiteman et Cooper 2000). L'apprentissage collectif diffère ainsi de l'apprentissage individuel présenté plus haut, lequel est basé sur la compréhension du fonctionnement systémique par les acteurs et le partage de connaissances.

Renforcement des capacités d'action

Les capacités d'action incluent les capacités techniques, financières et politico-administratives nécessaires au processus de cogestion adaptative. Pour que celles-ci correspondent aux problèmes des petites pêcheries rencontrés, au changement institutionnel et aux incertitudes de diverse nature, la construction et/ou le renforcement des capacités est un processus fondamental des régimes de gouvernance participative (Seijo et Salas 2014). Nos résultats ont montré que ce processus implique les différentes catégories d'acteurs impliquées dans la gouvernance, en particulier les pêcheurs et les agents administratifs chargés du développement et de la gestion des pêcheries (chapitres 2.1 et 2.2). Synthétiquement, les capacités visées remplissaient simultanément trois conditions :

i) spécialisées (e.g., méthodologies d'évaluations, règles de gestion appropriées, supports informatiques à l'analyse de données, connaissances biologiques et écologiques),

ii) rationalisées en fonction des contextes (e.g., compromis entre coûts et bénéfices socioéconomiques attendus, nombre des agents administratifs impliqués, moyens financiers mobilisables, contraintes logistiques d'intervention sur les sites, étendue socio-spatiale et complexité du système halieutique, nature et diversité des ressources),

iii) coordonnées horizontalement, verticalement, et temporellement (e.g., soutien politique et administratif manifesté par des textes réglementaires, interactions intersectorielles au sein des administrations impliquées dans le secteur des petites pêcheries, communication effective entre les différents niveaux de gouvernance, réactivité, mutualisation des capacités).

Le renforcement des capacités d'action requiert ainsi une approche holistique et sur le long terme du capital social, institutionnel et matériel approprié au développement institutionnel. Dans certains cas d'étude par exemple, la contribution d'acteurs extérieurs promouvant la participation des communautés locales (i.e., ONGs, projets de conservation des ressources halieutiques) a fortement soutenu l'engagement de leaders locaux dans la démarche expérimentale. Elle a ainsi renforcé les capacités globales d'action de l'intervention lorsque leurs actions étaient réalisées en collaboration étroite avec les administrations des pêches pilotant l'intervention (McConney et al. 2014 ; Finkbeiner et Basurto 2015).

4.2.4 Intervention et processus-clés du développement de la cogestion

Notre travail s'est appuyé empiriquement sur le modèle causal d'intervention (Figure 4) et a précisé son fonctionnement. Les quatre processus clés de la performance économique des régimes de cogestion des petites pêcheries étudiées (i.e., apprentissages individuel, apprentissage collectif, homogénéisation des stratégies des acteurs, et renforcement des capacités d'action) ont agi comme les véritables médiateurs du développement institutionnel. Ils opèrent de manière interdépendante et selon leur propre temporalité, à l'échelle pluriannuelle, en réponse aux aléas et aux contingences des pêcheries (en particulier les conditions initiales des interventions). Ces processus sont nécessairement progressifs et relativement lents en cas de changements institutionnels importants et de contexte défavorable en début d'intervention (Olsson et al. 2006 ; Abernethy et al. 2014).

Ces quatre médiateurs constituent en définitive une reformulation processuelle des nombreux facteurs identifiés affectant la gestion des ressources communes (e.g., Agrawal 2001 ; Cox et al. 2010). Cette reformulation éclaire la dynamique du développement institutionnel dans nos cas d'étude. Elle apporte selon nous les propositions suivantes comme guides de recherches futures sur la performance de la cogestion des petites pêcheries et sur ses capacités à répondre aux problèmes de surexploitation :

Proposition 1 - Les interventions efficaces sur la cogestion des petites pêcheries développent simultanément et avec succès les processus d'apprentissage individuel et collectif, d'homogénéisation des stratégies des acteurs, et de renforcement des capacités d'action pendant une durée suffisante (estimée empiriquement à un à deux ans dans nos cas d'étude).

Proposition 2 - Les interventions efficaces de politique des pêches sont mises en pratique à l'échelle des unités sociales. En dépit du rôle clé des autorités publiques mis en évidence dans l'initiation et/ou le développement des quatre processus ci-dessus, la vision d'une cogestion autoritaire, décrétée par les autorités publiques à l'échelle de larges unités politico-administratives et mise en œuvre uniformément dans les systèmes locaux, est en contradiction avec nos résultats empiriques.

Proposition 3 - Les coûts de transaction associés au développement de régimes de cogestion à large échelle, et dimensionnés aux bénéfices (e.g., biologiques, socioéconomiques) attendus, sont pris en charge par une intervention pluriannuelle. Le développement de partenariats avec des organisations horizontales et/ou verticales capables de structurer la participation des acteurs est une opportunité pour réduire les coûts supportés par l'intervention. Les moyens nécessaires à l'implication des administrations des pêches sur le long terme, postérieurement à l'intervention, doivent être anticipés pendant cette intervention.

La démarche d'expérimentation adaptative du développement institutionnel en conditions réelles relevant de la recherche-action est cohérente avec les trois propositions ci-dessus. Il s'agit d'une démarche prometteuse pour développer une approche holistique de la cogestion dans les systèmes halieutiques, à la fois tournées vers les acteurs locaux et les administrations (Armitage et al. 2008). La section suivante explore comment ce type de démarche de recherche peut être intégré plus largement aux politiques publiques intervenant dans le secteur des petites pêcheries de manière à mieux répondre à leurs enjeux de durabilité.

4.3 Connecter analyse et pratique de la gouvernance des petites pêcheries via une recherche transdisciplinaire

La position de la recherche halieutique (i.e., des chercheurs eux-mêmes, de leurs objets de recherche et de la connaissance scientifique produite) au sein du processus de gestion et de gouvernance des petites pêcheries a évolué de manière séquentielle. La récurrence des crises et le constat d'échec de nombreuses politiques de développement et de gestion ont en effet favorisé l'émergence de questionnements sur la production des connaissances halieutiques, leur traduction en régulations des modes d'exploitation, et les relations entre ces connaissances et les processus de décision (Troadec 1990 ; Clark 2006). La contribution la plus visible des chercheurs en halieutique les place souvent en position d'experts définissant les règles de gestion efficaces à mettre en œuvre à partir de considérations essentiellement écologiques et économiques. La recherche halieutique a d'ailleurs pu être jugée excessivement proche des instances d'administration et distante des usagers eux-mêmes, au point de négliger par exemple l'acceptabilité sociale des mesures de régulation (Catanzano et Rey 1997 ; Hutchings et al. 1997). Au contraire d'une indépendance parfois revendiquée et qui peut sembler confortable, ils font donc indiscutablement partie de l'arène sociale des systèmes halieutiques considérés comme objets de recherche. Ils y interviennent comme des acteurs modifiant, délibérément ou non, les relations sociales liées à l'exploitation des ressources.

Si la recherche-action sur les relations sociales entretient une proximité avec l'expertise en raison de sa perspective normative sur les usages des ressources naturelles et sur la gouvernance, elle s'en écarte significativement en raison de ses bases épistémologiques, comme explicité en introduction. La recherche-action partenariale, développée dans ce travail, est ainsi basée sur deux piliers : i) elle apporte aux acteurs (publics, privés et civils) des pêcheries et de la gouvernance un diagnostic contextuel des systèmes halieutiques jusque-là non disponible, et ii) elle mobilise cette connaissance au cours des processus du développement institutionnel décrits plus haut, en agissant sur les conditions d'un renforcement de la coopération entre les acteurs de ces systèmes (en particulier les pêcheurs et les administrations des pêches) dans le cadre d'expérimentations adaptatives. Selon son habilité et son expérience, le chercheur-acteur joue le rôle de pont entre les acteurs du système (Folke et al. 2005) et/ou d'entrepreneur institutionnel (Maguire et al. 2004) afin de créer un contexte favorable à la transformation des pratiques et au changement institutionnel. Comme montré dans nos travaux, l'intérêt de cette stratégie de recherche est sa contribution à la fois opérationnelle et analytique dans les enjeux de gestion et de gouvernance des petites pêcheries.

Bien que la recherche-action reste rare (sous cette appellation) dans le paysage scientifique halieutique actuel, son corpus méthodologique a été largement reformulé par la littérature

émergente sur la recherche transdisciplinaire sur la durabilité (Pohl et Hirsch Hadorn 2008 ; Lang et al. 2012). Comme la recherche-action, ce mode de recherche met en relation les acteurs scientifiques et non scientifiques pour la production, la légitimation, la diffusion et l'utilisation de connaissances de nature diverse, selon une démarche d'apprentissage définie en fonction des contingences locales. Nos résultats suggèrent que l'approche transdisciplinaire peut ainsi significativement contribuer à relier analyse et pratique de la cogestion des petites pêcheries.

L'orientation de la recherche vers l'étude des moyens de guider les interactions nature-sociétés le long de trajectoires durables se développe dans la communauté scientifique depuis une vingtaine d'années pour relever les grands défis du développement (Kates et al. 2001). Dans le domaine des pêcheries, cette orientation requiert un rapprochement entre les scientifiques et les autres acteurs des systèmes halieutiques, afin de promouvoir des actions à court terme, propres aux contextes, et mieux adaptées aux enjeux de durabilité (Mahon et al. 2005 ; Garcia et Charles 2007 ; Young et al. 2008 ; Johnson et al. 2013; Rice et al. 2014 ; Gasalla et de Castro 2016, Armitage et al. 2017c). Comme indiqué plus haut, les ONGs comptent parmi les acteurs émergents de ces systèmes, en particulier dans les pays du Sud, où elles interviennent de plus en plus dans la gestion des petites pêcheries depuis les années 1990 sous la forme de projets participatifs de gestion locale des ressources et/ou de conservation, éventuellement connectés à des scientifiques et/ou aux pouvoirs publics. De nombreux projets participatifs sur la gestion des petites pêcheries ont ainsi souligné l'intérêt des approches multi-niveaux abordant les problèmes localisés en termes collaboratifs (ou inversement, conflictuels), politiques, et de relations de pouvoir (Armitage et al. 2017a). Mais comment la recherche doit-elle procéder suivant cette direction pour que sa contribution et ses recommandations soient effectivement prises en considération par les acteurs administratifs et politiques qui définissent et appliquent les politiques publiques des pêches ?

Les recherches-actions développées dans ce travail (en particulier dans la Partie 2) apportent une contribution modeste à cette question fondamentale. Elles proposent en effet une approche qui aborde explicitement les questions de durabilité des petites pêcheries à la fois à l'échelle des politiques publiques et à l'échelle locale opérationnelle de gestion. Plus spécifiquement, cette approche constitue un moyen d'opérationnaliser une politique publique des pêches suivant le modèle causal exposé plus haut (Figure 4), et mis en œuvre par des expérimentations adaptatives de cogestion : l'approche a construit une stratégie d'action qui tenait compte des contingences locales et de l'arène sociale, impulsé des changements et mis en pratique une gouvernance multi-échelle, pendant une durée limitée. Notre pratique de la gouvernance était notamment basée sur l'approche par diagnostic institutionnel (Young 2008b), qui comporte des similarités avec de nombreux travaux sur la gestion concertée des ressources renouvelables (e.g., Mermet 1992 ; Beuret 2006 ; Castellanet et Jordan 2004).

A ce titre, un parallèle intéressant peut être effectué entre notre analyse institutionnelle empirique des relations entre intervention localisée et politique publique d'une part, et les analyses anthropologiques des projets de développement d'autre part. Ces dernières ont

montré l'écart entre la logique opérationnelle et fonctionnelle des projets de développement, liée à l'arène locale et aux processus socio-écologique locaux, et la logique des politiques publiques, qui justifie et valide les interventions localisées en construisant un contexte politique et d'alliances favorable, parfois déconnecté des impacts locaux de ces interventions (Mosse 2005). La performance de nos projets de recherche-action sur la gouvernance des petites pêcheries, et en définitive leur succès ou échec, dépendait ainsi de leur capacité à articuler ces deux logiques grâce aux processus du développement institutionnel mis en évidence plus haut. Notamment, la reconnaissance par les autorités publiques du rôle des acteurs locaux (dont les petits pêcheurs en premier lieu) et des pratiques institutionnelles développées s'est manifestée à travers la production de réglementations officielles et leur légitimisation par l'engagement de leurs représentants politiques, ce qui a renforcé la démarche (chapitre 2.2). La multiplicité des contextes locaux rend cependant cette nécessaire articulation difficile et coûteuse, comme illustré dans ce travail. Elle implique la difficile prise en compte d'intérêts contradictoires et évolutifs, dans le cadre d'actions collectives localisées et planifiées par les autorités publiques (Arce et Long 2000).

L'approche développée dans ce travail représente un effort de recherche pour mobiliser différentes sources de connaissances, académiques et non académiques, en favorisant la réflexion sur la production de savoirs sur les petites pêcheries et l'apprentissage de leur gouvernance partagée. L'insertion de la recherche dans des situations concrètes et des actions collectives a représenté un levier pour l'interdisciplinarité des regards (Weber et al. 1990 ; Bardhan et Ray 2008 ; Jollivet 2009). L'essor actuel des travaux de recherche collaborative et transdisciplinaire est une réelle opportunité dans cette direction, afin d'accompagner le dynamisme de la société civile et la nécessaire évolution des pratiques des administrations des pêches pour répondre aux enjeux de durabilité des petites pêcheries.

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Liste des acronymes

CBFM	Community-Based Fisheries Management
CFRs	Community fishery reserves
CPS	Secrétariat de la Communauté du Pacifique
FAO	Organisation des Nations Unies pour l'Alimentation et l'Agriculture
GBFM	Government-based fisheries management
GIS	Geographical information system
IRD	Institut de Recherche pour le Développement
ONG	Organisation Non Gouvernementale
MCA	Multiple Correspondence Analysis
ORSTOM	Office de la recherche scientifique et technique outre-mer
RB	Reference Biomass
TAC	Total Admissible de Capture
UMR	Unité Mixte de Recherche
VFD	Vanuatu Fisheries Department
VNSO	Vanuatu National Statistics Office

Liste des figures (hors publications)

Figure 1. Nombre de publications anglophones annuelles portant sur les petites pêcheries* répertoriées dans le Web of Science depuis 1995. On observe un net essor des recherches sur les petites pêcheries à l'échelle mondiale depuis une dizaine d'années, bien que cette tendance haussière doive être relativisée par rapport à l'accroissement général de la littérature scientifique mondiale.

Figure 2. Représentation conceptuelle d'un système halieutique ouvert (modifié d'après Rey et al. 1997 ; Charles 2001 ; Kooiman et al. 2005). Les flèches représentent des actions technologiques (en rose), des flux de produits halieutiques (en bleu), et des interactions sociales verticales et horizontales (en noir). Les sous-systèmes de production et décisionnel sont représentés.

Figure 3. Démarche de recherche-action (d'après Liu 1997 ; Dickens et Watkins 1999). Chacune des cinq étapes est réalisée de manière collective en impliquant des chercheurs et des acteurs du système halieutique. La durée de chaque cycle est indicative et flexible en fonction des actions planifiées et réalisées. Le système halieutique change typiquement d'un état i à un état i+1 après chaque cycle.

Figure 4. Modèle causal conceptuel du processus de développement institutionnel selon une démarche de recherche-action appuyant une intervention publique dans un cas donné (modifié d'après Stern et al. 2002). Les flèches indiquent les relations causales théoriques (cf. Figure 1 pour davantage de détails sur le système halieutique).

Figure 5. Localisation des trois cas d'étude en Nouvelle-Calédonie et au Vanuatu (Pacifique sud). Pêcherie locale de poissons récifaux au Vanuatu (cas 1), pêcherie locale d'holothuries en Nouvelle-Calédonie (cas 2), et pêcherie nationale d'holothuries au Vanuatu (cas 3).

Liste des tableaux (hors publications)

Tableau 1. Caractéristiques des cas d'étude incluant le contexte géographique et socioéconomique, les pêcheries étudiées et l'intervention.

UNIVERSITE SCIENCES BRETAGNE DE LA MER LOIRE ET DU LITTORAL

UBO Université de Bretagne Occidentale

Titre : Exploration de la performance de la gouvernance des petites pêcheries du Pacifique sud par une démarche de recherche-action.

Mots clés : Apprentissage social, changement institutionnel, cogestion, expérimentation adaptative, recherche transdisciplinaire.

Résumé : Notre travail est une contribution à l'élaboration d'un cadre de recherche pour étudier le développement institutionnel pour la cogestion des ressources halieutiques communes, qui reste un mode de gouvernance minoritaire à l'échelle mondiale malgré ses impacts positifs démontrés dans de nombreux cas concrets. Spécifiquement, la thèse examine la performance de la gouvernance de petites pêcheries suivant une approche empirique et inductive d'économie institutionnelle. Notre démarche de recherche-action a accompagné des interventions de politiques publiques des pêches sur la gestion de ressources récifales surexploitées dans plusieurs cas d'étude en Nouvelle-Calédonie et au Vanuatu (Pacifique sud) entre 2008 et 2016. Ces cas correspondaient à des contextes et des échelles spatiales et temporelles variables. La thèse s'appuie sur un modèle causal théorique des effets de ce type d'intervention sur le changement institutionnel dans les petites pêcheries, et sur une grille d'évaluation de la dynamique du développement institutionnel dans les cas d'étude. Elle propose une exploration à la fois analytique et pratique de l'expérimentation adaptative du développement de systèmes de cogestion en conditions réelles. Différentes sources de connaissances, académiques et non académiques, sont mobilisées, sur les petites pêcheries et sur l'apprentissage de leur gouvernance partagée. Les résultats montrent que la gestion spatialisée et multiéchelle des pêcheries récifales par cycles de fermetures et d'ouvertures temporaires de la pêche constitue une forme d'hybridation de la gestion communautaire et de l'intervention gouvernementale, adaptée à de nombreuses pêcheries mono ou plurispécifiques du Pacifique sud. Quatre processus clés soustendant la performance économique des régimes de cogestion des pêcheries étudiées sont mis en évidence : l'apprentissage individuel des processus systémiques, l'apprentissage collectif, l'homogénéisation des stratégies des acteurs, et le renforcement des capacités d'action. Ces processus opèrent de manière interdépendante et selon leur propre temporalité, en réponse aux aléas et aux contingences des pêcheries, qui déterminent notamment les conditions initiales des interventions. En abordant explicitement les questions de durabilité des petites pêcheries à l'échelle nationale et en même temps à l'échelle locale opérationnelle de gestion, la démarche de recherche adoptée propose des pistes de recherches effectivement transdisciplinaires sur la cogestion des petites pêcheries et sur ses capacités àmieux répondre aux enjeux de durabilité.

Title : Exploration of the performance of the governance of small-scale fisheries in the South Pacific through action research.

Keywords : Adaptive experimentation, co-management, institutional change, social learning, transdisciplinary research

Abstract : This work is a contribution for elaborating a research framework for the study of institutional development for the comanagement of common fishery resources. Indeed this governance mode is marginally being used worldwide despite its positive impacts that have been proved in a large number of concrete cases. Specifically the thesis examines the performance of the governance of small-scale fishery through an empirical and inductive approach of institutional economics. Our action research framework guided interventions of public fishery policy on the management of overexploited marine resources in several case studies in New Caledonia and Vanuatu (South Pacific) between 2008 and 2016.
Those cases corresponded to different contexts and temporal and spatial scales. The thesis is supported i) by a theoretical causal model of the effects of this kind of intervention on institutional change in smallscale fisheries, and ii) by an evaluation grid of the dynamics of institutional development in the case studies. It analytically and practically explores the process of adaptive experimentation of co-management development in real-life conditions. Academic and non academic knowledge on small-scale fisheries and the learning through shared governance is mobilized.
Results show that spatial, multi-scale management of reef fisheries through temporary openings and closures of fishing is a way to combine community-based management and government intervention that is relevant for a number of single- and multi-species fisheries in the South Pacific. Four key processes that drive the economic performance of fishery co-management regimes are highlighted, namely individual learning of systemic processes, collective learning, homogenization of actors' strategies, and building of capacity for action. These processes are interdependent following their own temporality in response to multiple stresses and fishery contingencies, that determine the initial conditions of the interventions in particular. By explicitly taking into account sustainability problems of smallscale fisheries at both the national and the local, operational levels, our research framework proposes truly transdisciplinary research guidelines on the co-management of small-scale fisheries and on its capacity for addressing sustainability challenges more efficiently.