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An appraisal of systematic conservation planning for Pacific Ocean Tropical Islands coastal environments

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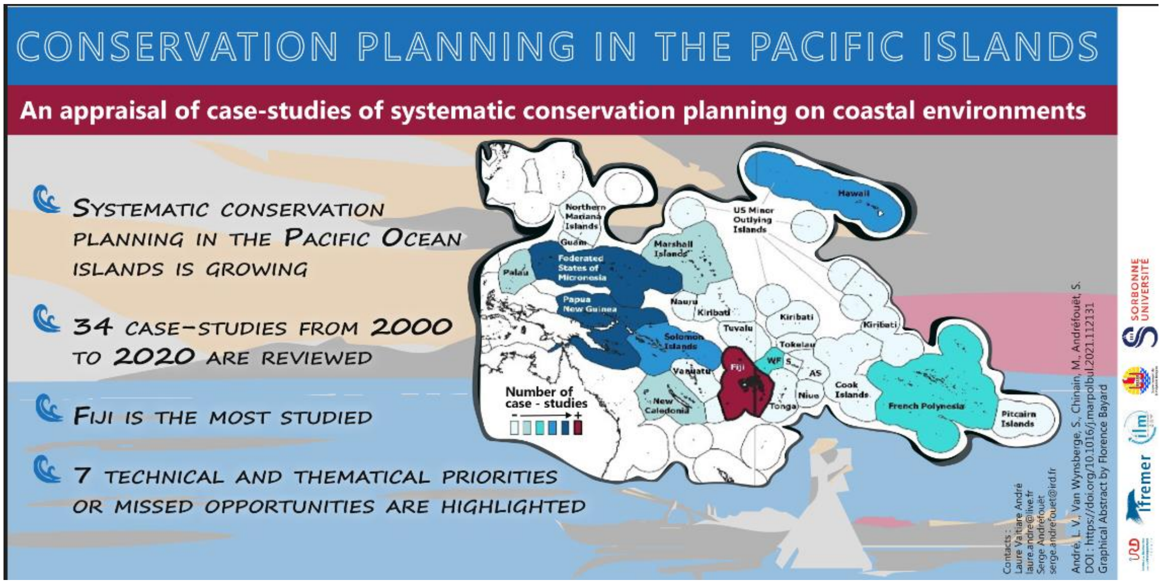
Abstract :

Systematic Conservation Planning (SCP) offers concepts and toolboxes to make spatial decisions on where to focus conservation actions while minimizing a variety of costs to stakeholders. Thirty-four studies of Pacific Ocean Tropical Islands were scrutinized to categorize past and current types of applications. It appeared that scenarios were often built on a biodiversity representation objective, opportunity costs for fishers was the most frequent cost factor, and an evolution from simple to sophisticated scenarios followed the need to maximize resilience and connectivity while mitigating climate change impacts. However, proxies and models were often not validated, pointing to data quality issues. Customary management by local communities motivated applications specific to the Pacific region, but several island features remained ignored, including invertebrate fishing, ciguatera poisoning and mariculture. Fourteen recommendations are provided to enhance scenarios' robustness, island specificities integration, complex modelling accuracy, and better use of SCP for island management.

Graphical abstract



Highlights

► Systematic conservation planning in the Pacific Ocean islands is growing. ► 34 case studies from 2000 to 2020 are reviewed. ► Melanesia (Fiji) is the most studied. ► Seven technical and thematical priorities or missed opportunities are highlighted.

Keywords : Pacific Ocean Tropical Islands, Spatial planning, Marine protected area, Aichi conservation target, Coral reef Fishery

Introduction

The Pacific Ocean Tropical Islands (POTIs) of Polynesia, Micronesia and Melanesia are characterized by their socio-ecosystems with populations traditionally highly linked to their environment, and by their small sizes, high geographical dispersion and endangered biodiversity, both across terrestrial and marine systems (Payri and Vidal, 2019). As of 2019, population densities are strongly contrasted between the largest cities and the most remote islands or rural areas (Andrew et al., 2019). Pacific islanders rely strongly on their marine environment for sustenance, income, culture, identity, exchanges with other islands, and coastal protection (Bell et al., 2009; Friedlander, 2018). The livelihoods and incomes of local populations are thus particularly vulnerable to any change in the availability of these marine resources, notably with respect to climate change, shifting weather patterns, demographic growth and overexploitation, and degradation due to economic development (Hanich et al., 2018). Islands are fragile, increasingly exposed to these threats, and increasingly face acute resource management and conservation issues (Kueffer and Kinney, 2017).

Conservation initiatives to mitigate various local and global threats are emerging. In some cases, they complement the customary management that is traditionally used to protect lagoon and reef areas as well as targeted species, with various levels of success (Bartlett et al., 2010; Hamilton et al., 2019; Sangha et al., 2019). National conservation initiatives are now also influenced by international guidelines on the conservation of biodiversity and ecosystem services, such as the Convention on Biological Diversity's Aichi Target 11, and the United Nations Sustainable Development Goal 14. These international objectives are aimed at preserving at least 10% of coastal and marine areas by 2020, including "ecologically representative areas of particular importance for biodiversity and ecosystem services", with "management equity and effectiveness; connectivity and integration into wider landscape and seascape (Rees et al., 2017), which are all aspects that can be relevant for POTIs.

To move conservation planning forward with increased effectiveness across different approaches requires Systematic Conservation Planning (SCP), a method that allows for a transparent, data-driven and objective decisions. SCP is based on prioritizing tools that identify optimal, or cost effective, priority conservation areas, by simultaneously setting conservation objectives around what to protect, with quantitative targets on how much to protect while minimizing the costs constraints of conservation (see Table 1). It relies on key concepts such as adequacy, comprehensiveness, representativeness, complementarity, vulnerability and/or efficiency (Kukkala and Moilanen, 2013). SCP implements the overarching goals of, for instance, representativeness or connectivity of biodiversity features included in conservation areas, through a number of specific quantitative and locally relevant targets, which can be measured and monitored (Margules and Pressey, 2000; Pressey and Bottril, 2009; Kukkala and Moilanen, 2013). Other approaches include conservation values aggregated across features and space (Moilanen et al., 2005). Threats to biodiversity have often been used as surrogates for conservation costs, though this correlation is now challenged (Sacre et al., 2019). Site selection is central to SCP and prioritisation can be calculated through mathematical models that balance objectives with the costs, providing sets of optimal and cost effective solutions. Analysis can be carried out via software that is specific for marine SCP (mainly Marxan and its extensions, Zonation, ConsNet, C-Plan or PrioritizR) where the search for optimal solutions can be performed multiple times resulting in a range of solutions. The solutions can take the form of i) a 'best'-case solution (solution with the lowest cost or maximum benefits, depending on the approach) and ii) a selection frequency, or priority rank map showing how many times an area is selected. The best solution is not necessarily the only one to consider, as the overall set of solutions can provide interesting alternatives of site selections. In the past few years, marine SCP studies have evolved in terms of complexity, and can now include a wide variety of objectives and socio-economic costs, as well as new criteria related to climate change, ecological connectivity between marine populations, and linkages within broader island-scapes through land and sea connections (Álvarez-Romero et al., 2018). Beyond the core SCP prioritization step, additional stages in the conservation process take place such as involvement of stakeholders, integration of plans across governance levels, implementation of conservation actions, maintaining and monitoring conservation areas with long term commitment (Pressey and Bottril, 2009; Weeks et al., 2014a). The scope of this review focuses primarily on the core SCP prioritization step and the other steps are not considered here.

SCP is increasingly present in the Polynesian, Melanesian and Micronesian POTIs. Given the current theoretical advances in SCP and the POTIs specifics, we assessed how SCP was used, and identified different strengths, weaknesses and gaps in SCP applications that managers, stakeholders and scientists should be aware of. Here, the main features of the POTIs are first presented as background information and then the technical specificities of the SCP case studies are synthesized and critically examined. When relevant, case studies derived from islands located in other tropical regions are also considered for discussion to complement the examples from the Pacific Ocean. Lastly, our recommendations for new directions are highlighted.

The context of Pacific Ocean Tropical Islands

1/ Geographical dispersion and physical diversity

In the tropical and sub-tropical Pacific Ocean, the Islands are first characterized by their geographical isolation with vast ocean territories included in their Economic Exclusive Zone (EEZ), which typically stretches from the shoreline to 200 nautical miles and in which they have jurisdiction over natural resources. The boundaries of our study area expand from 32°N (Northern Hawaii EEZ) to 35°S (Southern Kermadec Islands EEZ) and from 130°E (Palau) to 105°W (Easter Island). Our focus is primarily on tropical islands. We included several high latitude sub-tropical islands because they already harbor some tropical species in their waters, and this tendency is likely to increase with global warming (Payri and Vidal, 2019).

POTIs are characterized by their physical diversity, ranging from large continental islands with complex and extensive coral reef formations, to geologically recent oceanic volcanic islands surrounded by a narrow fringing reef, partially subsided volcanic land masses surrounded by a lagoon and a barrier reef, and atolls. These tropical marine ecosystems of coral reefs and related are of particular interest for biodiversity conservation.

2/ Governance

Administratively, POTIs are managed at national and/or territorial levels: they are either fully independent or autonomous countries, or territories that remain strongly linked to their overseas metropoles, several of those nonetheless possess their own governments (Table 2). Several countries also have strong customary laws at a local level, which ultimately often control the local use of marine resources. Pacific countries and territories, their privileged metropole counterparts, and Asia-Pacific superpower countries also often promote regional cooperation to enhance sustainable development.

Governance and enforcement required to manage environmental, marine, coastal and reef resources vary widely within POTIs. Some have efficient and dedicated technical services managing the environment and marine resources, while others lack competent technical services, relying on international aid programs, foreign NGOs, private consultants, and frequent training and monitoring via external funding often managed by international organizations (Table 2). Some Islands have developed innovative models of multi-level governance, such as Palau where resource users, the national government, and NGOs all take part to the management process (Gruby and Basurto, 2013). The lack of local available data and GIS facilities can make it difficult to compile local demography, environment and resource information (Table 2). This lack of spatial data can impact on requirements for SCP.

The small size of most islands implies that communities may have limited opportunities to replace any loss and damage to their natural resources, thus emphasizing the need for integrated management and conservation (Wenger et al., 2018).

3/ MPAs in the Pacific Ocean

Conservation areas, or Marine protected areas (MPAs), are defined as areas that are managed in order to reach the overall goal to protect biodiversity and manage marine resources. MPAs are important instruments for conservation and for sustaining marine resources for food security, particularly as POTIs have experienced considerable loss of biodiversity (Jupiter et al., 2014b; Payri and Vidal, 2019). In POTIs, MPAs can be managed through diverse levels of management from institutional government-level with international registries of the MPAs (listed in Table 2), NGOs, locally managed marine areas based on traditional marine tenure (such as village-based, customary, and sometimes hybrid management), as well as diverse levels of protection (no-take zones, partial protection zones for nursery areas, rotating closures, *tabu* zones, *rāhui* zones) (Friedlander, 2018; Gairin and Andréfouët, 2020; Jupiter et al., 2014a; Smallhorn-West and Gowan, 2018).

The number of very large MPAs (VLMPAs, defined here as >100.000 km²) has increased in the past decade, allowing, on paper, a quick convergence towards the Convention on Biological Diversity Aichi target 11 on protected areas. Eight of the world's current thirty-five VLMPAs are located in the tropical Pacific Ocean (Table 2) (MPAtlas, 2020). The POTIs' considerable EEZ areas offered solutions to satisfy the political engagements, but the pros and cons of these engagements have generated important debates, about the relevance of EEZ to represent species and ecosystems, for instance (e.g. Ban et al., 2017; Devillers et al., 2015; Singleton and Roberts, 2014). There is considerable differences in how POTIs manage their MPAs, several VLMPAS with official designation can have limited management plans whilst others already have much stricter policies, such as no-take area, like the Phoenix Island Protected Area in Kiribati (Rotjan et al., 2014).

4/ Coastal and reef fisheries, and mariculture

Sustainable fishing (including of finfish and invertebrates) is a cornerstone of current protein supply and future food security of Pacific Ocean Islanders (Bell et al., 2009). Despite many POTIs importing canned fish, most countries and territories still rely heavily on their local fisheries for economic development, revenue, job opportunities and food security, and islander livelihoods often depend on subsistence fishing, particularly from coral reefs (Bell et al., 2011b; Friedlander, 2018). For example, fish consumption is at least twice the World Health Organization recommended level in Tuvalu, Samoa, Niue, Wallis and Futuna, French Polynesia and the Federate States of Micronesia. Therefore, populations are vulnerable to any change in the status of these resources. Gillett (2016) underlined a remarkable drop of production per capita of coastal fisheries in the 2007-2014 period, suggesting decreased stocks and unsustainable fishing by a growing human population. Management of fishing stocks to achieve long term sustainability is hence among the top priorities for many local governments and communities. Adaptation measures in the face of climate change will also be required on a short-term, which includes shifting consumption towards species less vulnerable to fishing pressure and environmental changes, like tunas (Bell et al., 2018).

Mariculture production is not significant compared to other regions bordering the Pacific Ocean, especially Asia or South America (Oyinlola et al., 2018). At this time, 93% of the value of all mariculture is produced with both local and international markets in mind in two countries only (Gillett, 2016). In French Polynesia, mariculture is dominated by pearl oyster farming for the jewelry market, with 8250 ha of pearl farms in 2017, of which 74% located in the Tuamotu Islands (DRMM, 2017). In New Caledonia, production is dominated by shrimp farming with 1252 t. produced in 2015 (DAM, 2015). Mariculture remains a limited source of proteins for the local populations but is present in many places, at various development stages. It is often conducted at a small scale.

5/ Ciguatera poisoning

Ciguatera poisoning is widely present in the POTIs and results from the consumption of marine products that have accumulated lipid soluble toxins known as ciguatoxins. Yet, fish and also invertebrates highly prized by island communities such as bivalves (*e.g.* giant clams), echinoderms (e.g. sea urchins) and gastropods (e.g. trochus) have been found to be potential vectors (Darius et al., 2018). Ciguatoxins are produced by benthic dinoflagellates in the genera *Gambierdiscus* and *Fukuyoa* that grow preferentially within mixed algal turfs covering degraded coral substrates. Estimating the incidence of this disease is difficult because only 10-20% of cases are reported to public health or other authorities (Friedman et al. 2017). Across the Pacific islands, estimated true incidence rate reaches as much as 12,000 cases annually in the POTIs (Chinain et al., 2020), with the highest rates for Tokelau and Cook Islands (1,576 and 1,437 cases per 100,000 inhabitants, respectively) (Skinner et al., 2011). Ciguatera poses an immediate threat to human health, but also to islander livelihoods in the long run in the case of jeopardized access to safe local resources. Indeed, ciguatera occurrences are dynamic and a link was found between the toxic microalgae development and environmental disturbances, such as coral reef damage due to cyclonic waves, elevation of sea surface temperature, and coastal development (Bell et al., 2009; Chinain et al., 2010). As ciguatera varies spatially, it might influence opportunities for conservation and be an interesting spatial feature for SCP.

6/ Exposure to climate change

Climate change is expected to affect the Pacific Ocean in different ways and to greatly impact islanders, exacerbated by the socio-economic vulnerability and dependence to marine resources of many islands (Andrew et al., 2019; Bell et al., 2011a; 2011b; Hanich et al., 2018; Townhill et al., 2020). Many threats arise due to changes in oceanic and atmospheric circulations, which are expected to affect marine and coastal ecosystems. Increased sea surface temperature can cause more frequent coral bleaching, spread of pathogens, and mass mortality events. Increased dissolved CO_2 concentrations can lead to more acidic ocean with altered capacity of calcifying organisms to build skeletons and shells (Kleypas and Yates, 2009). Mariculture can also be impacted by these changes and adaptations, such as modification of the locations and diversification of production are required (Bell et al., 2011a). Rapid sea level rise could particularly affect reef islands and coastal environments, when the natural sediment production and dynamics are unable to compensate for the increased erosion of the soft-sediment coastlines (Garcin et al., 2016; Tuck et al., 2019). Sea level rise could also have serious implications on populations living on low lying islands, with planned migration being required to move people to safer areas (Weir et al., 2017). Climatic migrations, inducing land use change, could have important implications for conservation and could require spatial planning to manage this shift.

Literature review methods

To identify papers and reports on SCP applied to POTIs; literature searches were first performed from the Web Of Science® database with a variety of key-word combinations in the Title or Topic searched items. These combinations included: (1) the name of the targeted countries as displayed in Table 2; (2) 'Pacific Ocean'; (3) 'systematic conservation planning'; (4) 'costs'; and (5) names of planning softwares (such as 'Marxan', 'ConsNet' or 'Zonation'). Then, additional searches in Google® and Google Scholar® were performed with the same key words to identify additional reports or conference papers. All searches were restricted to the period 2000-2019. The reference lists and appendices of each publication were also scrutinized to detect previously unseen references, especially from the grey literature. The SCP database by Álvarez-Romero et al. (2018) at http://database.conservationplanning.org was also checked.

The relevance of all references provided by online searches was further checked on the basis of their title, abstract, and content. The studies were categorized in three types, which were not necessarily exclusive: 'SCP case studies' (for all papers using SCP framework for an analysis of a concrete case study), 'POTIs context paper' (for all papers related to the context specific to POTIs, but not presenting SCP *stricto sensu*), and 'SCP concept paper' (for all papers enlightening concepts that are useful for SCP in POTIs, but that are not necessarily located in the POTI region). Other valuable inputs for general background were papers presenting new concepts, ideas or approaches for conservation and management not necessarily using SCP (e.g. Adams et al., 2018), and papers that delivered reviews that could be complementary of our own objectives (e.g., broader geographical scope, e.g., Álvarez-Romero et al.; 2018). Several 'SCP concept paper' or 'POTIs context paper' initially identified were removed from the analysis when too general or providing redundant information. Similarly, for some SCP case studies available as both report and peer-reviewed paper, the most detailed ones were kept.

Once selected and classified by types, the full text of each SCP case study was screened to extract further details regarding study objectives and locations, methods and results. This included, when relevant, (1) country, (2) main topics and questions addressed in the study, (3) the nature of the study (i.e. methodological *versus* applied study), (4) authorship (academics, government, NGOs), (5) conservation objectives, targets, and types of costs, (6) the nature and origin of data used, (7) size of the planning domain, (8) size considered for planning units, and (9) success rate or effectiveness (sensu Kukkala and Moilanen (2013)), which refers to the extent by which objectives have been met.

After the initial search specifically targeting the Pacific Ocean, we also identified and kept a number of SCP case studies for tropical or sub-tropical areas outside the Pacific if they were focusing on topics, ideas, methods and data that were not found in the previously screened studies but could also be relevant for the POTIs. To identify these supporting studies, the same aforementioned key-words were used but with 'Coral Triangle', 'South-East Asia', or 'Indian Ocean' instead of Pacific country names. Caribbean Islands' studies were not searched. This geographically-widened search aimed to identify some relevant papers that could complement the exhaustive tropical Pacific Ocean search, for discussion purpose only.

Results

This review collated 85 peer-reviewed papers and 10 reports. Among them, we found 34 studies describing POTI SCP case studies (SCP prioritization *stricto sensu*: describing the selected features, objectives, costs, software etc.), and providing a portfolio of different SCP objectives, methods, scale, and study sites, presented in Table 3. The topics addressed by these POTI SCP case studies have been itemized (Supplementary Material S1a). We also identified and short-listed a non-exhaustive list of 12 POTIs context papers and 28 SCP case studies for tropical or sub-tropical areas beyond POTIs, but focusing on topics that were relevant for the POTIs. The topics raised by these papers are also itemized (Supplementary Material S1b) and used for the discussion.

Among the 34 POTI SCP case studies, most of them appeared primarily driven by academic authors for methodological and scientific research purpose (n=23), and not necessarily related to actual implementation. A majority of studies were conducted by academic authors only (n=19). This trend seems to increase with time. A number of studies were conducted by academic authors but with local authorities (n=8), NGOs (n=2) or both (n=3). Few studies were conducted only by NGOs (n=1) or NGOs and local authorities (n=1). Most of the studies were at assessment stage, while few (n=6) seemed to be at almost-implementation stages. Some of these reports were consultancy reports for local governmental ministries and agencies (n=12) (e.g. Government of Papua New Guinea, 2015).

The analyses of the technical specificities of each SCP case study highlight that (1) there is a wide variety of scales for spatial domains: from few km² (28 km² in French Polynesia) up to country scales (2,510,750 km² in Papua New Guinea) and for planning unit (PU) size (Table 3). Four groups can be distinguished. Studies used : PU size < 10,000 m² or even less (n=7), PU size: 10,000-100,000 m² (n=9), PU size: 100,000-1,000,000 m² (or 0,1-1 km²)(n=17), and few used PU size > 1 km² (n=6) (counting the different values sometimes used in a single study). We found that PU sizes roughly grow with spatial domains, which is the same trend as reported globally by Álvarez-Romero et al. (2018). (2) The primary objective from which all results will depend on is often an Aichi 11 representation target: most plans (83%) were designed to target a given percent representation of habitats. (3) There is a great discrepancy in country coverage. Specifically, while many POTIs have no identified studies (n=16/26; 47%; Figure 1), particularly in Polynesia, where 77% of the countries had no SCP case studies (Figure 2a), Fiji is by far the most represented country (n=14/34; 40% of all the studies). Melanesia thus accounts for 60% of studies (Figure 2b). (4) Many case studies relied on proxies and modelling (80%), and very few have specifically collected or validated new *in situ* data for their investigations (n=7) (Table 3).

We categorized the themes tackled by each POTI SCP case study (Supplementary Material S1a). The main ones are presented below, ranked by number of occurrences, keeping in mind that more than one topic could be found in any given study:

- Identification of low cost marine conservation areas using SCP designs (n=13)
- Influence of socio-economic costs and proxies in SCP design efficiencies (n=12)
- Ridge to reef approach for integrated land and sea planning (n=9)
- Integration of resilience criteria and connectivity in SCP designs (n=7)

- Socio-economic and cultural consequences of conservation plans (socio-economic equity, etc.) (n=7)
- Comparison of solutions between SCP and other approaches (n=6)
- Influence of habitat map resolution/thematic richness on SCP designs (n=5)
- Benefits of integrating local knowledge in SCP (n=5)
- Conservation gap analysis (n=4)
- Benefits of integrating a variety of actors and stakeholders in SCP designs (n=3)
- Scaling-up conservation networks between local and regional scale (n=3)
- Integration of climate change information on SCP designs (n=3)
- Adaptive management and SCP designs (n=2)

Several of these topics also emerged in a global review of the recent marine SCP literature (Álvarez-Romero et al., 2018), which highlights that the same issues are of concern worldwide. However, there are POTI specific issues (see Discussion). Although the relatively limited number of case studies in this region impedes robust quantitative analysis, several patterns emerge (Figure 2). The geographical occurrence and abundance of studies vary over time between the three regions (Figure 2c). Among the analysed themes, most of them have been tackled mainly in Melanesia, and either in Micronesia or Polynesia, or both. Adaptive management has been discussed only for Melanesia, precisely in Fiji.

Discussion

This paper presents a summary of the current state of the art and SCP practices in POTIs, organized following the list of topics highlighted above. These topics include objectives and targets, gap analyses, cost functions and proxies, conservation network scaling, habitat map resolution and the integration of connectivity, resilience, climate change and adaptive planning. However, we also detected gaps in the SCP applications in POTIs. Avenues for improvements are discussed throughout, for each section and further discussion is made on issues such as data quality, planning unit size and shape, model validation, and missed opportunities. Examples from other regions outside the Pacific (Supplementary Material S1b) are used to highlight similar or alternative procedures, improvements and future developments also worthwhile to consider for POTIs. Note that we do not discuss here how much SCP has contributed in actually implementing conservation measures, due to the difficulty (i) to assess the actual degree of how much a SCP exercise could have influenced it, or even (ii) to assess reliably the number of MPAs in the POTIs (Smallhorn-West and Govan, 2018).

Setting (arbitrary) conservation objectives and targets

In the POTIs, most SCP case studies focus on protecting a certain proportion of biodiversity. This is generally achieved through the use of goals similar to the Aichi Target 11: by selecting areas that represent a given percent of the surface area of a number of key habitats that have been previously mapped, and thus are available in a spatial format unlike most other biodiversity data sets. These habitat maps act, in fact, as surrogates of biodiversity (see section Habitat). The targeted level of representation can vary greatly, typically between 10% and 30% depending on the studies. In South-East Asia, the Coral Triangle Initiative recommended 10% (Weeks et al., 2010a), or 20% (Horigue et al., 2015) representation of all habitats. This choice is actually rarely debated on even though it induces considerable spatial differences in terms of results (e.g. Hamel et al., 2013). It remains unknown, however, if these levels of habitat representation can achieve an exhaustive representation of biodiversity and its related services, or how much of it (Dalleau et al., 2010).

In addition to habitat representation targets, some studies have tried to include qualitative objectives, notably by integrating representativeness, connectivity, and climate change considerations. For instance, targets are sometimes defined to be 10-100% protection of biodiversity features, 50-90% of connectivity pathways, 30-100% of areas resilient to global warming (Magris et al., 2017), 50% of critically important sites (e.g. fish spawning aggregations) or 95% of endangered turtles nesting beaches (Lipsett-Moore et al., 2010). These approaches can lead to Multiple-Criteria analyses. For example, both socio-economic equity and management effectiveness could be set as fishing activity costs. This has been proposed for transboundary Indian Ocean large domains (e.g. from Kenya to South Africa, to east of Maldives and Chagos), to include 50% of reef areas in sustainable fishing areas and 20% in conservation zones (Jones et al., 2018). Other plans have proposed as an objective to include 10% of coral reef-associated habitats and an increasing percentage of fishing grounds remaining open for fishers, in the Philippines (Weeks et al., 2010b). However, the problem is the same as for habitat representation: there is generally very little available rationale to select one percentage of representation over another for a given objective that management focus on, and guidelines for trade-offs are few. Within a fishery context, rationale for quantitative objectives of stock conservation, or important zones to sustain fish populations such as spawning areas, are lacking. The lack of clear thresholds is explained by the natural variability of the system and the consequences of different fishing levels.

Conservation gap analyses

Conservation and data gap analyses aim to identify the areas where data and conservation activities are lacking; these can be used to prioritize actions. As such, gap analysis is a critical preliminary step before SCP. To illustrate this point, two types of studies can be mentioned: one methodological paper based on metadata and habitat maps (Andréfouët and Hamel, 2014) and several case studies. The latter encompass variable scales, methods, and goals. For instance, Cleguer et al. (2015) focused on specific conservation gaps (for dugongs) in New Caledonia. Others identified broader data and conservation gap at national and ecosystem scales (e.g., Government of Papua New Guinea, 2015). Various POTIs have been the subject of such assessments since 2000, including for instance the Marshall Islands, Solomon Islands, Papua New Guinea, and Fiji, often with the goal of generating SCP scenarios (Government of Papua New Guinea, 2015; Jupiter et al., 2010; Kool et al., 2010; Reimaanlok National Planning Team, 2008). Data synthesis meant for *ad hoc* selection of conservation priority areas are less formalized, and often based on expert opinion. These correspond to ecoregional analysis (for New Caledonia for instance, Garrigue et al., 2005) or bioregionalisation (Wendt et al., 2018) that also can be seen as a spatial planning approach different from SCP.

Importance of socio-economic costs and their proxies

Different types of costs, that planners aim to minimize, are relevant in SCP (Naidoo et al., 2006). However, our review showed that costs were most frequently defined as fishery opportunity costs (Table 3). Minimizing opportunity costs to fishers is assumed to increase their compliance and ensure their support with respect to MPA implementation, resulting in a more effective conservation plan (Weeks et al., 2010a). Costs are always recognized to greatly influence SCP outputs (Cheok et al., 2016; Deas et al., 2014; Gurney et al., 2015), and they are not free of incidental consequences impacting more stakeholders than fishers alone (Hamel et al., 2018). Opportunity costs to fishers are most often incorporated using fishery data based on proxies, which can be crudely defined. In most papers, authors had no option but to use proxies because of the lack of socio-economic data and lack of resources to acquire such data (Mills et al., 2010; Weeks et al., 2010a). Indeed, it is worth noting that except for Deas et al. (2014), spatially explicit catch data have not been used to estimate opportunity costs although this would have been the most unbiased way to derive a fishery value. The background data for Deas et al. (2014) were an atlas of the catches for a New Caledonia area (by weight, fishing gears, species, etc.) (Guillemot and Leopold, 2009). Unfortunately this type of coastal fishery atlas remains extremely rare as most socio-economic surveys are not translated into maps (e.g. the Procfish surveys, as in Kronen et al. (2009)), or offer only very coarse results (Aswani and Lauer, 2006). As sustainable reef fisheries are a cornerstone of Pacific Ocean islander's food security and livelihood, it would be extremely valuable to create and update such fishery atlases, before running SCP scenarios.

When no fishery data are available, simple proxies are widely used as opportunity costs, such as population density or travelling distance (Cheok et al., 2016). In that respect, the value of the chosen socio economic proxy is a key question (Hamel et al., 2018; Maina et al., 2015), although its relevance and precision is rarely evaluated or put to the test. Weeks et al. (2010b) compared in a Philippines case study, spatially homogenous cost and population census data with empirical data and concluded that commonly used proxies poorly reflect fishery empirical costs that were estimated with surveys. Likewise, Deas et al. (2014) showed that a poor choice of proxy could disadvantage fishers even more than a scenario constrained without any proxy of socio-economic costs to minimize. When no socio-economic data are available, the proxy commonly used is the surface area. In a Madagascar case study, proxies of fishing pressure came from a combination of motorized and non-motorized coastal fishing units (Allnutt et al., 2012). Other studies developped more sophisticated proxies models in Fiji for instance, to represent food fish abundance and probability of catch, depending on fishing gear types and market values (Adams et al., 2011). Other fishery aspects related to the spatial and temporal dynamics of fishing pressure, never considered thus far, could be used. This includes the effects of the reserve on fishing effort displacement. This has already been assessed as critical when trying to conserve stocks (Van Wynsberge et al., 2013).

Costs are more often defined with fishers in mind, but the use of the marine domain in a variety of ways is a hallmark of POTI societies. An emergent recommendation is that it can be necessary to integrate in the design the interests of a variety of actors and how they value their environment (Buijs, 2009; Gurney et al., 2015; Hamel et al., 2018; Weeks et al., 2010b). Taking into account multiple stakeholder groups instead of a unique one is a sound path towards a more equitably distributed conservation cost.

Scaling conservation networks

'Scaling' reflects the dynamic two-way relationship that may exist between local and regional scales in terms of assessment and implementation. It is a complex series of topics that are strongly relevant for countries consisting of islands, such as the POTIs. It addresses for instance a MPA network extension from *ad hoc* local solutions to regional solutions (Mills et al., 2012), the frequency at which regional priorities need to be updated as local actions are implemented (Cheok et al., 2017), or how conservation costs vary locally for a collection of local scenarios *vs* an overarching regional scenario (Kabbadj et al., 2018).

The question of extending existing networks of conservation areas has emerged as a scaling challenge in SCP. Very often, MPAs in developing countries are numerous but they are characterized by a very small size and were not designed to integrate, for instance, representativeness and connectivity. The challenge is especially acute in the POTIs, due to traditional management which is frequently dependent on local tenure. In Islands, local marine tenure and customary use of the sea have to be considered given their social importance, especially in Melanesia (Jupiter et al., 2014b). However, a fragmented network of locally managed small protected areas are unlikely to protect effectively mobile species, nor represent all the ecological processes upon which local biological populations depend (Léopold et al., 2017). Locally managed areas can also be very vulnerable to local and global stressors if there are no nearby sources for the replenishment of populations. The growth, or scaling-up of the network in a coordinated manner is necessary to mitigate these problems. The case of Fiji is interesting here because it stands out with the highest number of case studies (Figures 1, 2a; Table 3). This can be explained by the fact that the pre-existing *qoliqoli* traditional management areas needed to be integrated in overarching conservation projects, but also by a favorable context of science driven conservation NGOs and involved academics, who elaborated, step by step, a number of data layers and SCP scenarios, in cooperation with communities, private and state stakeholders.

Working on a larger domain can also theoretically spread the costs of conservation and can offer more flexibility when a range of solutions meeting the conservation objectives, are sought for. In practice, however, coordinating and merging in a conservation framework local tenures means that there will be overlap and interaction with other types of governance when the size of the targeted domain increases. These interactions are specific to each country and will depend on local administration entities and their competences (Horigue et al., 2015; Mills et al., 2014; 2012; Weeks and Jupiter, 2013). These complex interactions can be a serious limiting factor for implementation. For instance, in New Caledonia, lagoon and coral reefs conservation is a Provincial competence, hence there are not yet any marine trans-provincial conservation area despite the reef and lagoon continuum (Gairin and Andréfouët 2020). Furthermore, the small size and the isolation of POTIs are also critical limiting factors when spatially expanding conservation networks, as space is limited to find possible solutions.

There are both practical advantages and limitations of working at a regional or local scale (Mills et al., 2010). Adequate understanding of scale-related issues and trade-offs can improve local conservation within regional plans, while promoting the implementation of ecologically functional networks (Mills et al., 2010), for instance by taking into account connectivity (Margules and Pressey, 2000). This argument, however, is valid only if there are enough data to characterize meaningfully and accurately these processes, which is often not the case. Some studies argue on the necessity of assessing data and provide data gap analysis to evaluate the availability and quality of the data before using it for SCP (Andréfouët and Hamel, 2014; Geange et al., 2017). This important issue of data quality will be further discussed in a next section. Conversely, working regionally may relax the need for high spatial resolution data that would be necessary for small local conservation areas.

Currently, there are no clear general recommendations for scaling-up an existing network, given the variety of configurations (geography, governance, existing networks, etc). General principles can be outlined, such as finding a trade-off between acceptability of costs and the ecological viability of many small reserves (Weeks et al., 2010a). For instance, it has been shown that spreading heterogeneously conservation costs throughout different tenures to meet an overarching regional conservation objective can easily generate inequities locally (Kabbadj et al., 2018). Unequal outcomes and benefits can be a major reason to reject conservation programs (Gurney et al., 2015).

Habitat data used in SCP scenarios

SCP scenarios often aim to protect a certain percentage of the surface of each habitat, in particular to obey an objective similar to a type of Aichi Target 11, i.e., habitat representation. Habitats are implicitly or explicitly used as a surrogate of biodiversity in conservation. In practice, habitat maps are used, and these data sets are the baseline for most scenarios (see above). Therefore, habitat map information, and understanding what is this information, should be critical.

The quality, and the relevance of a habitat map for a given conservation problem, is related principally to its thematic resolution (i.e., the number of habitats considered), thematic information, spatial resolution, coverage, and accuracy. There are trade-offs between all of these factors. For instance, a highly complex map of several tens of benthic habitat classes (high thematic resolution) at 1 to 4 m. resolution (very high spatial resolution), covering a full country (high coverage) and with an accuracy >95% for every habitat class (very high accuracy) probably do not exist, and are not doable without prohibitive ground-truthing campaign costs. It is necessary to make application-specific compromise between all these factors when creating habitat maps (Andréfouët, 2008). Furthermore, for a given site, many different types of maps can co-exist and all can be valuable in conservation context (e.g. for Wallis Island in Dalleau et al., 2010). Eventually, SCP scenario results are very dependent on the set of maps used and on their characteristics, and this has been quite abundantly discussed (Andréfouët et al., 2012; Deas et al., 2014; Hamel et al., 2013; Hamel and Andréfouët, 2012; Tulloch et al., 2013).

Several of the POTIs studies have used coral reef geomorphological habitat data from the Millennium Coral Reef Mapping Project (Andréfouët et al., 2009; Cheok et al., 2016; Deas et al., 2014; Gurney et al., 2015; Hamel et al., 2013; Horigue et al., 2015; Lipsett-Moore et al., 2010; Tulloch et al., 2016; Weeks et al., 2016). There are maps at high geomorphological thematic resolution, low spatial resolution (considered to be at 100m, as the products come from Landsat 7 ETM+ satellite image at 30m resolution), with full coverage of islands and countries. Some studies have added to this inventory of geomorphological reef habitats, maps of seagrass and mangroves (Allnutt et al., 2012), intertidal areas (Makino et al., 2013b) and spawning and nesting sites (Green et al., 2009). Other studies have used different benthic habitat maps created at much higher spatial resolution (few meters), at high thematic resolution (Deas et al., 2014 in New Caledonia), at local to national coverage (e.g. Maina et al., 2015 in Kenya) and with medium to good overall accuracy (60-95% depending on the classes) (Tulloch et al., 2013 in Fiji).

Other studies do not use habitat as a conservation objective but rather use it as a base to infer features related to marine resources, such as the distribution of focal reef species (Weeks et al., 2016), giant clam density, biomass and recruitment (Kabbadj et al., 2018), catch per unit effort (Gurney et al., 2015), fishing pressure (Van Wynsberge et al., 2015), exposure to thermal stress, biological richness (Hamel and Andréfouët, 2012), biodiversity value (Allnutt et al., 2012), reef class resilience score (Weeks and Jupiter, 2013), and resilience to climate change (Lipsett-Moore et al., 2010).

Sensitivity analysis of SCP solutions to different habitat map characteristics should be more systematic, although there are already some examples. Andréfouët et al. (2009), Deas et al. (2014), Hamel et al. (2013) and Mills et al. (2010) all found that thematic and spatial resolution of habitat maps influence the results. Deas et al. (2014) compared SCP solutions generated from geomorphological maps and from benthic habitat maps, and confirmed that high thematic resolution increases the fragmentation of the solution network, and can limit management effectiveness. Mills et al. (2010) recommended to use available data - often only available at a coarse-resolution - as a first step, and then to acquire new fine-resolution data. Finally, Tulloch et al. (2013) specifically looked at the influence of map accuracy on reserve network design. Solutions were easily influenced if prioritizations accounted for habitat map accuracy. However, in the case of known poorly accurate map, it may be simply advised not to use such maps.

Planning unit size and shape

The type of planning units and their sizes impact the resulting design. Rationales for selecting PU sizes are listed in Álvarez-Romero et al. (2018). From the POTI SCP case studies, a very wide range of size is used while overall, there are few sensitivity analysis to this important parameter (but see Cheok et al. 2016). Hamel et al. (2013) showed that the PU size was a preponderant criteria when trying to optimize trade-offs between conservation objectives and costs, around Wallis, Futuna and Alofi Islands. Sizes can vary greatly between studies but the trend is that choosing small planning unit size allows for more satisfying trade-offs (Van Wynsberge et al., 2015). In terms of shape, PUs are frequently square or hexagonal. Most of the time, the choice of the shape is rather arbitrary and not justified. Van Wynsberge et al. (2015) compared two designs for small islands and concluded that an irregular shape PU network (that are equally acceptable as input for the SCP softwares), based on coral reef geomorphology and data availability, was more suitable because data quality was less impacted, compared to the necessary spatial averaging to match the spatial format of a regular grid.

Towards more complex scenarios: representativity, connectivity, resilience, climate change and adaptive planning

International guidelines recommend the integration of a number of qualitative objectives to optimize a network of ecologically or biologically significant marine areas (EBSAs). These core concepts include representativity, connectivity replicated ecological features, adequate and viable sites, and more (Kukkala and Moilanen, 2013; Rees et al., 2017). Indeed, it is widely recognized that area-based objectives alone are not sufficient to identify optimal areas to sustain marine ecosystems processes and services (Rees et al., 2017). Representativity is a key concept in SCP and is defined by the Convention on Biological Diversity Parties as being 'captured in a network when it consists of areas representing the different biogeographical subdivisions of the global oceans and regional seas that reasonably reflect the full range of ecosystems' (UNEP/CBD/COP/DEC/IX/20/Annex II). It is a core concept of prioritization, found in all SCP scenarios at different biological levels (species, communities, habitats, etc.). Conversely, resilience and connectivity are criteria that have been considered more recently, including for POTIs, to refine scenarios and represent key dynamic ecological processes and functions in a network, generally at a fairly wide scale.

Resilience is the capacity of an entity to resist to disturbances or recover and bounce back after disturbances (O'Leary et al., 2017). Maximizing resilience within a network can be an objective in SCP, but naturally resilient areas can be seen as low priority conservation areas compared to degraded ones. Since West & Salm (2003), principles for designing MPA networks to maximize resilience have been developed including i) replicate major habitats to spread risks, ii) incorporate patterns of connectivity, iii) include critical habitats, and iv) reduce the overall level of threats (marine or land pollution, unsustainable or destructive fishing, coastal development, etc.). POTI examples of resilience-based networks exist in Papua New Guinea (Green et al., 2009) and Fiji (Weeks and Jupiter, 2013). In Indonesian Islands, Torres-Pulliza et al., (2013) also built on these principles and ensured that coral reefs, mangroves and seagrass beds would be enough replicated at close distance. In practice, the applications of resilience-based principles on any given site are strongly limited by the lack of knowledge, even for the most studied ones (see section on data quality and modelling). Instead, rules of thumb, and proxies, are usually applied (Green et al., 2009), for instance by taking into account the longest and shortest dispersal distances, thus with a minimum size per MPA and a maximum spacing distance between different MPAs (Mora et al., 2006).

However, similar to other type of modeling and choice of proxies, there are virtually no validation data to justify the choices for most of the sites. Weeks & Jupiter (2013) recognized that without a large disturbance event, it would be impossible to measure whether the resilience of their targeted area increases with the suggested MPA network.

Connectivity is a core process of landscape ecology and population dynamics as it depicts how populations are linked, with the movements of larvae, recruits, juveniles or adults (Pinsky et al., 2012). Connectivity is seen as a key factor of resilience and recovery, mitigating the impacts of stressors in the long term, including climate change. Pathways of larvae and adults, as well as reproduction sites are therefore included in SCP plans in the form of specific representation objectives to maximize connectivity in the network of solutions. Within marine ecosystems, there is a considerable degree of functional and spatial connectivity depending on species, locations, and scales (Rees et al., 2017). It is however, difficult to set general parameterization for connectivity considering there are often many species of interest with varying dispersal patterns (Magris et al., 2016). Instead, specific objectives are needed for demonstration (Weeks et al., 2016), but the solutions can be inherently very specific to the selected species and contexts, and possibly of limited practical relevance for real-world implementation if the biodiversity conservation objectives are broad.

Another approach related to connectivity and rising in the POTIs and worldwide (Álvarez-Romero et al., 2018), is to adopt a “ridge to reef” logic and take into consideration that land has an impact on streams, rivers, shores and the surrounding marine ecosystems with soil runoffs, nutrients, pathogens, and sediment plumes. Some studies are fairly simple based on coastal watershed, rivers, and forest cover or types (Comeros-Raynal et al., 2019; Klein et al., 2012; Lipsett-Moore et al., 2010; Tsang et al., 2019). In Fiji (Makino et al., 2013a) and in Hawaii (Tsang et al., 2019) studies compared SCP without connectivity and with different types of connectivity, including land-sea connectivity. They concluded that connectivity had a huge influence on the solutions computed for habitat representation objectives. Some have modelled the future watershed based-pollution as projected with future land uses such as logging (Wenger et al., 2018, in the Solomon islands) or agriculture, in particular oil palm development in Indonesia, with a wide number of parameters to estimate erosion and pollutant sources, coastal transport plume model etc. (Tulloch et al., 2016). While it seems that high islands only would be concerned by a ridge-to-reef approach, in fact, low-lying atolls can also have significant land-based pollution that have triggered ecological shifts in some lagoons (Andréfouët et al., 2017). While the type of data and model would be very different for an atoll from for a high-island, land-sea linkages remain a concern for atolls too. Further, in the implementation stage, the success of integrated land-sea management is largely subject to the type of governance, as demonstrated for three islands in the POTIs (Jupiter et al., 2017).

Climate change stressors and resulting changes on communities have been taken into account in a variety of designs in islands and tropical coasts worldwide (Allnutt et al., 2012; Álvarez-Romero et al., 2018; Kabbadj et al., 2018; Levy and Ban, 2013; Maina et al., 2015; Makino et al., 2014). Principles to include climate change projections in SCP designs in the POTIs have been first discussed by Levy & Ban (2013) at regional scale. They used sea surface temperature historical patterns, one coupled atmospheric-ocean general circulation models (CAOGCM) and one emission scenario to infer future anomalies and vulnerability to climate stress. However, this pilot study needs to be enhanced. In particular, CAOGCM are notoriously inaccurate for the central Pacific and specific approaches are needed to meaningfully downscale and characterize anomalies for islands (Andréfouët et al., 2015; Dutheil et al., 2019). These precautions are required to identify suitable robust areas with SCP. This is only one of the challenges. Understanding capacities to adapt over present ranges of environmental conditions is critical (Kleypas et al., 1999). The location of possible refugia might be also a key resilience question, and there are, for instance, limited knowledge on the resilience potential of mesophotic areas on the deep areas around most islands (Slattery et al., 2011).

Finally, adaptive planning is a relevant concept for islands facing climate change, resources collapse or socio-economic changes (Mills et al., 2015). Adaptive planning means that new data, socio-ecosystem changes, natural disasters and so on may call for new decisions, assessment and implementation. For instance, the poleward, or latitudinal, shift of communities and habitats is a process already occurring (in Japan and Australia at least) (Nimbs and Smith, 2018), that certainly calls for re-assessment and adaptive planning in the future (Makino et al., 2014). The concept is also inherent to the amount of time required between regional assessment and local implementation, which may call for frequent re-assessment, and changes of objectives (Cheok et al., 2018). In the POTIs, adaptive planning has been emphasized for Fijian coral reefs (Weeks and Jupiter, 2013) but not all the challenges could be overcome in this case (Mills et al., 2015). On the ground, there are several POTIs examples of zoning plans that have been revisited in the past although without using SCP (e.g., Moorea lagoon in French Polynesia, about 15 years after the first zoning). It is most likely that many existing conservation plans will have to be modified, perhaps at a frequency of 10-15 years. The technical challenges are the same as for a one-time conservation evaluation, but are multiplied by the need to understand the natural or anthropogenic triggers for adaptation, convince stakeholders that changes are needed, evaluate the effectiveness of the previous plans, and so forth. Despite the challenges, anticipating the almost unavoidable needs to update plans should be a methodological priority in SCP for POTIs.

House of cards: modelling without validation, and the issue of data quality

Looking at the chronology of the various studies (Supplementary Material S1a), there is a clear trend towards more complex scenarios with time, both in the POTIs and globally (Álvarez-Romero et al., 2018). This is likely partly due to academic objectives (publications having to introduce novelties) and not necessarily driven by the most urgent manager needs. In parallel with more complex questions, more complex modelling is being developed for SCP inputs, but is often not based on new *in situ* validation data, and does not always take into account the adequacy of used data sets (in scale, content and accuracies). It seems that in many cases, working out a new idea is by itself a justification to conduct an exercise, regardless of data quality. This is even more worrisome when model outputs are 'stacked' together in order to include complex modelled layers such as vulnerability to climate change, soil erosion, land cover maps, sediment transport pathways, lagoon hydrodynamics, ecological behaviors (such as fish movements), socio-economic information (such as fishing patterns), etc. (e.g. Klein et al., 2014b; Levy and Ban, 2013; Tulloch et al., 2013; Weeks et al., 2016). While the management problems at stake are certainly relevant, the methodology of the study can suffer from serious shortcomings in the absence of any clear model validation. Inferences for management recommendations should be avoided when there are no proofs that the model outputs are robust and accurate, or without in-depth sensitivity analyses. Obviously, collecting the right and validated information can be a time-consuming expensive effort, but it should not be forgotten for real applications. On the other hand, there also are many POTIs studies that have carefully modelled new data layers which can be useful for conservation (e.g. Knudby et al., 2011). We recommend that i) model validation should be imperative before management conclusions are drawn and ii) that adequate quality data must be collected for validation purposes.

A possible effect of complex modelling papers used for new conceptual developments is that managers may believe that without extensive complex scenarios and complex data layers, they cannot achieve sound spatial planning through SCP tools and use its guidance potential. Similar misconception also occurred, for instance, in habitat mapping using remote sensing that was often seen as a high-tech endeavor (Andréfouët, 2008). Conversely, and perhaps because it is not original anymore, very useful studies for management that make basic uses of the SCP tools are poorly represented in the list of recent SCP publications. For instance, sensitivity studies identifying trade-offs between solution performances and socio-economic costs remain extremely useful, even in simple fishery contexts (e.g. Hamel et al., 2013; Oyafuso et al., 2019).

Another data-related issue also highlighted by Álvarez-Romero et al. (2018) in their review, is the lack of proper documentation on the parameterization and setting of SCP software options, such as Boundary Length Modifier and Species Penalty Factor used by Marxan. These options influence the solutions and their documentation contributes to data quality improvement. Detailed reports in this regard are often more useful than the typically concise peer-reviewed papers (e.g., for Palau, Hinchley et al., 2007).

Missed POTI opportunities for SCP, and perspectives

Overall, two types of studies could be clearly outlined in the present review. First, academic-driven studies are dominant, without much of a manager involvement, which seems to push SCP towards more complex scenarios and assess the feasibility to integrate new constraints and paradigms (adaptive planning, climate change, resilience, ridge-to-reef continuum, genetics models, etc.). The second type of papers are case studies which are more in line with the founding SCP concepts of evaluating conservation gaps and comparing objectives *vs* cost trade-offs, especially for fishery and stock conservation. Similar trends were also noted globally by Álvarez-Romero et al. (2018). The latter, simpler, types of applications are also more in line with the main basic priorities, often put forward by island managers. Indeed, they often primarily have to deal with balancing marine resource conservation and food security with other types of activities (tourism, coastal development, mining, etc.). As such, it is likely that the simplest types of SCP scenarios will continue to be used to provide a sound foundation for decision making in partnership with various stakeholders. However, when comparing island specifics and criteria used in SCP scenarios, we suggest that seven important gaps, or missed opportunities, emerge, which we believe should shortly require some attention from SCP practitioners.

First, biodiversity criteria (either as objectives, costs of exploitation, or biological processes) are often limited to habitats (see above) or biased towards fishes. Yet, from the POTIs context, there is a variety of potential relevant criteria. To our knowledge, there are almost no SCP studies built around echinoderms, crustaceans, mollusks (but see Kabbadj et al., 2018), or marine mammals though scientists, NGOs and government acknowledge that these are also priorities for management (Weeks and Adams 2018). For instance, sea cucumber fisheries are significant in many archipelagoes, and while the status and management of this resource is frequently debated (Andréfouët et al., 2019b; Bosserelle et al., 2017; Purcell et al., 2013), no SCP studies have focused on this taxa, or used population data. Similarly, several critically endangered species, such as dugong in New Caledonia, are the focus of many conservation projects (e.g., Cleguer et al. 2015), yet, relevant information such as feeding and reproduction areas, or migration pathways, have not been used in SCP scenarios, except for turtle nesting beaches (e.g., Green et al., 2009). Lack of spatialised data readily available likely hinder the development of appropriate scenarios.

Second, mariculture has never been used in any SCP scenario in the POTIs, either within a conservation or fisheries management approach. Outside the POTI region, Indonesia brings an example of mariculture integrated to SCP, with seaweed and pearl farming (Grantham et al., 2013). Mariculture in island lagoons or coastal areas is at various stages of development in many Pacific Ocean places and have often only occurred at small scale in the past decades (Adams et al., 2001). In the past 20 years, black pearl farming in French Polynesia, Cook Islands and Fiji, or shrimp farming in New Caledonia have developed over large areas and have become economically significant. For instance, black pearl farming in French Polynesia is the 2nd source of income for the country with activities in about 35 islands (Andréfouët and Adjeroud, 2019). A most likely path for development in the POTIs is the aquarium trade, for which areas for valuable specimen collection, spat collection, or rearing are increasing (e.g., Teitelbaum and Friedman, 2008, for giant clams). Even if mariculture remains today marginal in many countries, the future needs for local stock enhancement, the proximity of the Asian seafood and jewelry market, the extent of shallow lagoons offering suitable locations, the possibility to grow high value products in small areas with simple technology, and an interest for local populations to work with marine resources, could increase the need to account for mariculture in future SCP scenarios. For instance, given the extent of black pearl farming activities in many French Polynesian lagoons, it is likely that specific SCP scenarios for optimal zoning according to this activity will emerge soon. These could also take advantage of hydrodynamic 3D models implemented to compute connectivity matrices for pearl oyster larval dispersal (Dumas et al., 2012; Thomas et al., 2016), as well as genetics study that can help mapping populations and larval dispersal source and sinks (Reisser et al., 2020). In the context of different uses and zones that require *ad hoc* management, such as mariculture, fishing and conservation zones specific SCP tools can help, such as Marxan with Zones.

Third, ciguatera spatial risk has never been integrated into SCP. For islands where there are ciguatera-endemic areas, it can be stated that these areas are *de facto* protected as *no take* (or 'less take') areas, since they tend to be avoided by fishers. Hence, SCP scenarios could take advantage of the situation by maximizing the inclusion of areas known to be ciguateric, to decrease the fisher opportunity costs. Several other factors obviously need to be considered, including i) the habitat quality and its suitability as a conservation objective, in case ciguatera was due to coastal degradation, and ii) the availability of spatially-explicit ciguatera toxicity data, which are difficult and costly to collect and spatialize. If this information could be collected from fishers, who should care about and know ciguatera spatial patterns, even approximately, it could benefit to SCP and might influence opportunities for conservation. We can generalize this point about ciguatera to any factors (environmental, cultural or historical) that transform areas into *de facto* no take areas for local populations.

Fourth, molecular data are increasingly available for POTIs and have long served conservation (Von der Heyden et al., 2014), but methods to include genetics and genomics data in SCP have only been emerging recently (Beger et al., 2014) and, to our knowledge, no example is available for the POTIs, yet. Molecular data are necessary to understand connectivity at population and evolutionary time scales and validate connectivity models (Treml et al., 2015, Reisser et al. 2020), which could improve SCP to a great extent, depending on the scale of the exercise. However, considering the cost of sampling and analysis especially for population genetics, investigations can only be performed for a limited number of species, and the choice of candidate species is not trivial if the conservation objective is general and not specific to those species. Multi-species modelling could be a solution, as discussed for South Africa (Nielsen et al., 2017). However, other limitations arise, such as differences in the density of samples per planning domain or planning unit, especially for multiple island exercises.

Other island-specific aspects have already emerged in SCP scenarios but still remain understudied or underrepresented and could define future additional roadmaps for POTIs scenarios as highlighted below.

Fifth, while the need to consider customary management has been emphasized in several SCP scenarios with, for instance, locked-in areas (Adams et al., 2011; Green et al., 2009; Horigue et al., 2015), there is also a large amount of work to be done about the scaling of conservation network, especially in several of the POTIs that have not been yet the object of SCP studies. In Vanuatu for instance, traditional micro-managed areas are the norm, are plentiful (Dumas et al., 2010) and will not be easily abandoned for other schemes. Understanding how to maximize the benefits of existing initiatives is a priority. In Polynesia region, existing protected *tapu* (or *tabu, taboo)* or *rāhui* (temporal closures) areas, have also been ignored thus far by SCP studies, while some local initiatives have recently revitalized these traditional practices (e.g. in French Polynesia: Bambridge et al., 2019). Nevertheless, in the context of sessile or sedentary fishery management, the effectiveness of temporal, rotating or permanent closures compared to other measures such as catch size limits and quotas, is still debated (Carvalho et al., 2019; Plagányi et al., 2015; Purcell et al., 2015; Van Wynsberge et al., 2013). Cultural values are still strongly anchored in many island societies despite the fast evolution towards a westernized, globalized, modern way of life (Buijs, 2009; McFarlane et al., 2019). However, cultural values remain poorly considered in POTI SCP scenarios (Hamel et al., 2018) although they could be difficult to integrate due to ongoing change, varied tenure and governance systems, and strong bottom-up approaches to management. Interestingly in Fiji, mixed co-management systems exist, including for joint land-sea managed areas (Jupiter et al., 2014a; Weeks, 2017). Anthropology studies have characterized how local communities can value their marine environment for reasons that are beyond just access to food, identifying locations of high symbolic value (Foale et al., 2011), but this information is often not spatialized though it would be valuable for SCP.

Sixth, SCP has never been used for the zonation of VLMPAs in the POTIs (listed in Table 2). Even globally, the only example is the rezoning plan of Great Barrier Reef Marine Park Authority in Australia (Fernandes et al., 2005). In POTIs, none of the boundaries or zoning plans (if any) of the VLMPAs or sanctuaries were designed using SCP methodology. Political decisions were made without much of spatial planning scientific prioritization. Considering the sizes of these MPAs, and the limited amount of conflicting stakeholder activities (if no fishing license or seabed mining), a SCP driven selection was often not justified. However, most need to define zoning plans and a SCP approach has been recommended for their definitions as well as for the identification of new VLMPAs (Davies et al., 2017; Devillers et al., 2015). It is likely that SCP will play a role for this, although the biggest challenges remain collecting suitable biological data across wide expanses of ocean, to build relevant and robust scenarios. Biodiversity models have been used at the scale of VLMPAs (e.g., Davies et al., 2017), but, again, data quality remains an issue and it might be better to focus on the representation of bio-physical regions defined by mapped physical and geomorphological features (Devillers et al., 2015). It is likely that in the near future, the problems inherent to optimizing conservation *vs* costs, and inferring management plans for these VLMPAs, will be under the scrutiny of the SCP community. Recent studies have proposed new definitions for bioregions in the Pacific Ocean (Beger et al., 2020; Garcia et al., 2018), that could help refining VLMPAs planning, based on representativity, but the relevance of these bioregion definitions remain data quality-dependent.

Seventh, and last, POTIs are highly vulnerable to climate change. While some island examples of climate change-driven SCP scenarios emerge from this review (Hawaii, French Polynesia and Fiji, respectively with Chung et al., 2019; Kabbadj et al., 2018; Weeks et al., 2013), their number is not congruent with the threats that represent warming, changes in cyclone activities and potentially sea level rise (Payri and Vidal, 2019). Adaptive planning would also have to be considered if SCP considers climate change effects at various time scale. For instance, while the effects of sea level rise on low lying islands are still scientifically debated (Tuck et al., 2019; Masselink et al., 2020), this process could accentuate the effects of poor land use (Yamano et al., 2007) and of tectonic activities that are also a feature of several POTIs, such as Vanuatu (Ballu et al., 2011). Increased occurrences of flooding could trigger population migrations, which raise important questions on potential destinations, availability of land and tenure (Connell, 2016; Donner, 2015), including a change on the use of resources and potential for conservation. SCP could be useful to plan these migrations that could occur in the future at different spatial scales (within and between islands).

The main recommendations emerging from this review on POTI SCP are summarised in Table 4. Several recommendations echo previous reviews not specific to POTIs (Álvarez-Romero et al., 2018). However, they are reinforced from the present review. Furthermore, we also emphasised both thematic and methodological priorities, namely the need to still consider basic SCP applications, document well the projects, conduct sensitivity analyses and, most importantly, use accurate data to, at least, validate the proxies or model outputs used for SCP. Among the most critical recommendations inferred from this study, adaptive planning concepts should be part of the long term implementation of conservation plans, even for the most basic ones. Islands and populations are inherently dynamic in the present context of climate change and increased resource exploitation, thus revisiting conservation plans will necessarily be mandatory, at least every decade or more often. 'Plan for new plans' as we could put it, is essential.

Conclusion

Systematic conservation planning is a mature scientific tool that has demonstrated high flexibility in the accommodation of a variety of data, features and processes relevant to conserve and sustain ecosystems while minimizing the impacts for stakeholders. It is only one part of the conservation toolbox and other approaches can also work quite well for assessment and implementation. For instance, expert-driven *ad hoc* solutions can emerge more easily and simplify the work of managers, though this approach has limitations (Allnutt et al., 2012; Keppel, 2014; Keppel et al., 2012; Klein et al., 2014a). The potential, pros, and cons of the various approaches remain a matter of debate and this will likely continue in the future, however, SCP provides useful advantages.

This review of SCP application in POTIs shows strong potential despite limited uptake in POTIs (Cheok et al., 2018; Margules and Pressey, 2000). In terms of geographic polarisation, the present analysis is consistent with the conclusions from Álvarez-Romero et al. (2018): studies are concentrated within a few areas; in particular in Fiji at the POTI's scale analysis. In other countries, there might be shortage of technical competences and initiatives as those found in Fiji. In some countries, conservation took the path of implementing Very Large Marine Protected Areas, a path that is not necessarily exclusive of smaller local initiatives, but has dominated the political, if not the technical, conservation agenda.

In the future, understanding the reasons why SCP has not emerged in some places will also help conservation agendas, along with adequate data collection, storage and management.

The present review points to several possible bottlenecks that are expected to drastically limit the generalization of the more complex scenarios and adaptive planning. First, good data sets are limited. There are no shortage of research questions useful to enhance conservation and SCP (Weeks and Adams, 2018), but a lack of data and knowledge to provide answers to those questions. Modelling and proxies are often used to fill data gaps, but there are shortcomings due to the inherent limitations of models and proxies. Collection for any scenarios of relevant accurate 'hard' data of known errors is therefore highly recommended here. Enough resources should be allocated for initial data collection, especially for baseline data that often seemed to be granted, such as habitat maps, biodiversity, or fishery data. For instance, a systematization of the spatialisation of the socio-economic surveys, especially those related to fisheries (such as in Léopold et al., 2014), should be a priority.

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Figure 1. Map of the POTI Exclusive Economic Zones and the census of reviewed systematic conservation planning case studies conducted for each one, from 2000 to 2019. For each value, the number of POTIs concerned is given in brackets.

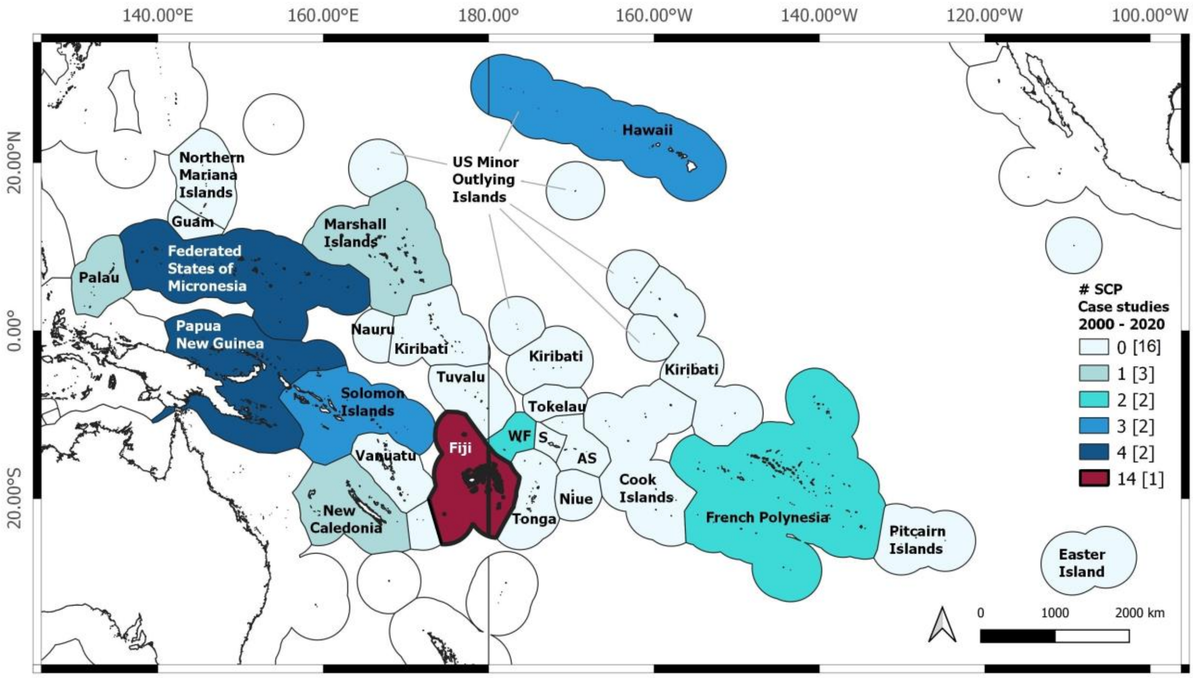

Figure 2. a. All the Pacific Ocean tropical Islands (POTIs) classified by region (POTIs in Polynesia = 50% as there are 13/26 POTIs that are located in Polynesia), and the proportion of POTIs that have been subject to SCP are indicated in colour, POTIs not subject to SCP in blank; b. All the reviewed POTI SCP case studies classified by regions; c. Number of SCP case studies through time, with a coloured indication for each region, and case studies concerning Fiji highlighted by a grey frame; d. Summary of the SCP case studies organised according to their regions and the themes tackled. Themes are presented with key words here, they are further developed in the result section.

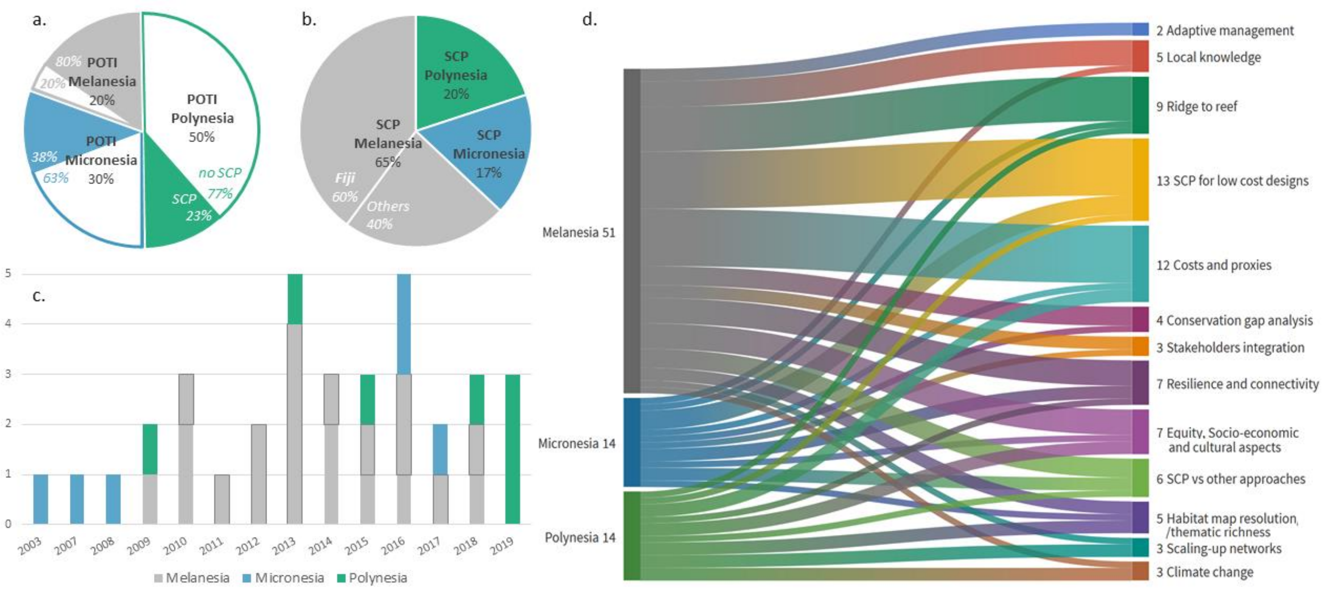

Table 1. Definition of SCP vocabulary.

Term	Definition
Conservation objective	Qualitative goal, referring to general principles of conservation, such as international policy objectives, representativity objectives etc. It describes the type of feature to protect (e.g., geomorphic habitats, mangroves...), as used by Margules and Pressey (2000).
Conservation target	Quantitative goal, to protect biodiversity. Often a percentage, between 10 and 30%, of the area of each feature that needs to be selected for conservation.
Cost	The constraint/negative outcome expected to be generated by the conservation objective and target. Cost is sought to be minimized in the design of SCP. Cost include acquisition costs, management costs, transaction costs or monetary (or in any other value) (Naidoo et al., 2006). It is usually measured through opportunity cost to fishers, but it could also be cultural or spiritual as well.
Opportunity cost	What could have been gained but become foregone opportunities when a conservation plan is implemented (Naidoo et al., 2006).
Spatial/planning domain	The total area considered by the analysis.
Planning Unit	The geometric division of the overall spatial domain into individual regular spatial domain where management decision are applied. Planning units are classically either square or hexagonal shape. Their size can vary from less than 1 km² to hundreds of km², depending on the scale of the study.
Resolution	In SCP, it is used either as spatial resolution (minimum size on the ground of measured data), or thematic resolution (number of categories).
Scale	Can cover several meaning (see Cheok et al. 2016). Here, local-scale is used when the spatial domain includes one island or less; regional scale includes one or more archipelagos (which consist of at least two islands).
Scenario	A combination of all of the above, which defines the specific context of a SCP case study. Numerical modelling information also defines the SCP scenarios when performed with planning software, such as number of iterations.
Assessment	The design phase of conservation planning including spatial prioritization (Cheok et al., 2018).
Implementation	The translation of assessments into actions on the ground such as the implementation of protected areas (Cheok et al., 2018).

Table 2. The POTIs main features. SPC= Pacific Community, FFA= Pacific Islands Forum Fisheries Agency, WCPFC= Western and Central Pacific Fisheries Commission (Y for Participating territory, not member), Environmental/fishery technical services (Y* for existing services but few/no specific information available), SCP= Systematic conservation planning, MPA= Marine protected areas, VLMPA: very large MPA, WHS= UNESCO World Heritage Site, MAB= UNESCO Man and Biosphere Reserve. NC= New Caledonia, NZ= New Zealand; USA=United States of America; UK=United Kingdom. MPA= all categories, including IUCN ones.*

		Political levels								
		Regional level								
Group	**Countries or territories**	**SPC**	**FFA**	**WCPFC**	**Status**	**Env/fishery technical services**	**National marine GIS database**	**SCP case studies**	**MPA, VLMPA, shark/marine mammal sanctuaries (sanct.), UNESCO WHS and MAB (area in km²)**
Melanesia	Papua New Guinea	Y	Y	Y	Independent	Y*	N	4	MPA; Whale sanctuary
Melanesia	Solomon Isl.	Y	Y	Y	Independent	Y*	N	3	MPA; WHS: East Rennell (370)
Melanesia	Vanuatu	Y	Y	Y	Independent	Y	N	0	MPA; Marine Mammal sanct.
Melanesia	New Caledonia	Y	N	Y*	French overseas territory	Y	Y	1	VLMPA: Natural Park of the Coral Sea (1,368,806); WHS: Lagoons of NC (15,740) ; Shark sanct.; Whale sanct.
Melanesia	Fiji	Y	Y	Y	Independent	Y	N	14	MPA
Micronesia	Palau	Y	Y	Y	Independent	Y*	N	1	MPA; VLMPA: Palau Nat'l Marine Sanct. (475,000); MAB: Ngaremeduu (137); WHS: Rock isl Southern Lagoon (1002); Shark sanct.; Marine Mammal sanct.
Micronesia	Federated States of Micronesia	Y	Y	Y	Independent	N	N	4	MPA; VLMPA: Micronesia MPA (184,948); MAB: Utwe (18); And Atoll (10); Shark sanct.
Micronesia	Guam	Y	N	Y*	Unincorporated territory of the USA	Y	Y	0	MPA
Micronesia	Commonwealth of the Northern Mariana Isl.	Y	N	Y*	Unincorporated territory of the USA	Y	Y	0	MPA; VLMPA: Marianas Trench Marine Nat'l Monument: (250,000); Shark sanct.
Micronesia	Marshall Isl.	Y	Y	Y	Independent	Y	N	1	MPA; Shark sanct.
Micronesia	Nauru	Y	Y	Y	Independent	N	N	0	N
Micronesia	Kiribati	Y	Y	Y	Independent	Y	Y	0	MPA; Shark sanct.; VLMPA-WHS: Phoenix Island protected area (408,250)
-	USA Minor Outlying Isl.	N	N	Y	Unorganized territories of the USA	Y	Y	0	VLMPA: Pacific Remote Isl. Nat'l Monument, (1,270,000)

Polynesia	Tuvalu	Y	Y	Y	Independent	Y*	N	0	MPA
Polynesia	Wallis and Futuna	Y	N	Y*	French overseas collectivity	Y	Y	2	N
Polynesia	Tonga	Y	Y	Y	Independent	Y*	N	0	MPA; Whale sanct.
Polynesia	Samoa	Y	Y	Y	Independent	Y	N	0	MPA; Whale, Turtle and Shark sanct.
Polynesia	American Samoa	Y	N	Y*	Unincorporated territory of the USA	Y	Y	0	MPA; Shark sanct.; Whale and Turtle sanct.
Polynesia	Tokelau	Y	Y	Y*	Realm of NZ	Y	Y	0	Shark sanct.; Whale sanct.
Polynesia	Niue	Y	Y	Y	Independent	Y*	N	0	Whale sanct.
Polynesia	Cook Isl.	Y	Y	Y	Independent	Y	Y	0	VLMPA: Marae Moana, (1,900,000); Shark sanct.; Cetacean sanct.
Polynesia	French Polynesia	Y	N	Y*	French overseas Country	Y	Y	2	MPA; MAB: Fakarava Reserve (15,948); Shark sanct.; Cetacean sanct.
Polynesia	Pitcairn Isl.	Y	N	N	UK overseas territory (Non self-governing)	N*	Y	0	VLMPA: Pitcairn Island Marine Reserve (834,334)
Polynesia	Easter Island	N	N	N	Special territory of Chile	Y	N	0	MPA; VLMPA: Motu Motiro Hiva Marine Park (150,000)
Polynesia	Hawai'i	N	N	N	USA State	Y	Y	3	MPA VLMPA: Papahānaumokuākea Marine Nat'l Monument (1,508,870)
Polynesia subtropical	Kermadec Isl.	Y	Y	Y	NZ outlying Isl.	Y	Y	0	MPA; VLMPA: Kermadec Benthic protected area (620,000)

Table 3. Review of the technical features of 31 SCP case studies on POTIs. PU= Planning units, DDPU= data driven planning units, BLM= Boundary Length Modifier, CSM= Connectivity strength modifier, CPUE= catch per unit effort, PNG= Papua New Guinea. FSM= Federated States of Micronesia, NGO=non-governmental organization. MCRMP= Millennium Coral Reef Mapping Project, LMMA= locally managed marine areas, MPA= marine protected area, nb= number, min.= minimum, max.=maximum, obj=objective(s), cons.= conservation, hab.= habitats, ecosyst.= ecosystem, comm= community/ies, sp.= species, gov.= government, spag= spawning aggregation sites. For Success rate of objectives, only the quantitative results clearly presented are provided.

Date	Authors	Country or Territory	Methodological/ Applied paper (M/A)	Institutional context	Marine conservation objectives (nb)	Origin of the map	Conservation targets (%)	Costs: Proxies? Validation?	Other constraints	SCP software + version	Spatial domain (km²)	PU size (m²) (shape), BLM (y/n)	Success rate of objectives
2003	TNC	FSM	A	NGO	Ecological systems, comm. & species (53)	-	20-30%	-	-	-	29,175	-	38% sites are protected
2007	Hinchley et al.	Palau	A	Academic with NGO & gov.	Ecosystems, hab., species & special areas (39)	1:25,000 USGS, Landsat7	30-100%	28 socio-economic factors	Existing reserves	SPOT + Marxan	3114	15,000 m² BLM	NA
2008	Reimaanlok Nat'l Planning Team	Marshall Isl.	A	Academic & gov.	Coarse scale (hab./ ecosyst.) (10), fine scale (sp./ rare comm./ cultural point) (6), sp. (21)	IKONOS, Quickbird, LandSat & ASTER; Landsat7 for coral reefs	30-100%	Socio-economic costs, distributed among comm.	Existing reserves	-	14,067	-	30-100%
2009	Andréfouët et al.	Wallis	M, A	Academic & gov.	Geomorphic hab. (MCRMP, level 5) + benthic map (56). 9 biological inventories	MCRMP	20%	Management costs (minimal size of the MPA; cost = BML)	-	R	269	250,000 1,000,000 & 4,000,000 m² BLM	NA
2009	Green et al.	PNG	A	Academic with NGO		-	-	15 data layers combined to derive a total cost layer (detailed socio-economic surveys)	-	Marxan	13,000	100,000 m² (hexagon). BLM Min. size of MPA ; Max spacing dist.	NA
2010	Lipsett-Moore et al.	Solomon Isl.	A	Academic & NGO with Tribal Communities	Marine cons. features (114) (47 coral reefs derived by 4 bioregions)	MCRMP (coral reef types); experts (bioregions)	10-95%	PU area minus PU proportion of rapid inclusion in the protected area network.	Existing, proposed, protected or managed areas	Marxan & Zonae cogito	7 894	500,000 m² BLM	NA
2010	Jupiter et al.	Fiji	M, A	Academic & NGO	Hab. (11) & sp.	Workshop participants	25-100%	-	LMMAs	-	-	-	NA
2010	Kool et al.	Solomon	A	Academic,	Functional hab.	MCRMP	10-50%	No costs for the	Reserves	Marxan	60,638	2,500,000 m²	NA

		Isl.		NGO + gov.	types (8)			marine part				BLM	
2011	Adams, et al.	Fiji	M, A	Academic	Hab. (7)	Aerial photographs (Fiji dept. of Lands & topographic map sheets)	30%	Modelled opportunity cost, modelled profit, CPUE with multiple gear types (surveys)	Existing Tapu areas (partly open for fishing) & no take MPA	Marxan	262	2500 & 62,500 m²	NA
2012	Klein et al.	Fiji	M, A	Academic	Coral reef attributes (4)	Landsat 5 Thematic Mapper (30m.) (for land)	Maximize coral reef condition	Fishing pressure (proxy: inhab. density) Distance-based plume (model)	-	-	7759	1,000,000 m²	NA
2012	Mills et al.	Fiji	M	Academic & local authorities	Ecosystem types (8)	"all available data" (see Mills et al., 2011)	30%	Socio-economic cost (proxy: distance to road / village)	Reserves: locked in or not.	Maxent Marxan with Zone	30	500,000 m²	Ecological effectiveness scores varied from 0.10 to 1.
2013	Tulloch et al.	Fiji	M, A	Academic	Benthic habitats (33)	QuickBird 2006, Ikonos 2007,transects (Knudby et al., 2011)	10-99%. Certainty target: 50-99%	Equal cost	-	Marxan v.2.43 , Marxan with Prob.	114	5000 m² (hexagon)	NA
2013	Hamel et al.	Wallis, Alofi & Futuna	A	Academic & local gov.	Geomorphic map (Wallis: 16, Alofi: 4, Futuna: 3) Geomorphic + benthic map (W: 55, A: 6, F: 3)	Landsat 7 ETM+ (30m.), MCRMP, benthic map from aerial photos (2m.)	20%	Fishing grounds (objective: keep all subsistence fishing grounds open for extraction)	3 small informal customary MPAs in Wallis	ESRI R ArcMapTM 10.0 & R, Marxan	300	250,000 & 40,000 m² (square)	Only 60% of the cons. obj. achieved when all fishing grounds open for W&F, 20% for Alofi.
2013	Weeks & Jupiter.	Fiji	A	Academic, collaboration with local chiefs, & NGO	Fish, invertebrate abundance & coral cover.	-	30% of 10 coral reef classes	uniform socio-economic costs, (validated then with workshop)	Reserves	Marxan	273	-	NA
2013	Makino et al. (a)	Fiji	M, A	Academic	Reefs (2) & forest (1); with adjacent-reef symmetric land-sea connectivity	-	30% (reefs) 20% (forests)	Cost of land; foregone fishing revenue (model)	-	Marxan, with connectivity value matrix	2971	1,000,000 m² (hexagon); CSM	NA
2013	Makino et al. (b)	Fiji	M	Academic	Marine hab. (5)	-	30%	Opportunity cost (fishing pressure surrogate, coastal pop. model)	LMMA, permanent, semi/open access areas.	Marxan with Zones	10,044	1,000,000 m²	NA
2014	Deas et al.	New	A	Academic	Geomorphic (26)	Quickbird	20%	Opportunity cost	ustomary	Marxan	211	216,000 m²	NA

		Caledonia			& geomorphic + benthic (106)	(2.4m.) MCRMP		(19 layers, fisheries atlas)	exclusive fishing area			(hexagon) BLM	
2014	Klein et al.	Fiji	M, A	Academic & gov.	Vegetation types (7)	-	40%	Clan cost (tenure negociations) & equal cost	Protected Areas: locked in	Marxan	Approx. 16,400	1,000,000 m² BLM	Up to 2.8x better for reefs, with land-sea connection.
2014	Mills et al.	Solomon Isl.	M, A	Academic	Coral reef types (8); and in-degree centrality	MCRMP	12-30%	Equal cost; and inverse of in-degree centrality	-	Marxan		2,500,000 m² (hexagon) BLM 0	NA
2015	Gurnay et al.	Fiji	M, A	Academic	Geomorphic reef classes (9); or CPUE	MCRMP	10-90% hab. or: 90% min. of CPUE	Conservation objectives or CPUE		Marxan, Marxan with Zones	260	60,000 m²	60% (cons. obj.) & 90% (CPUE obj.)
2015	Government of PNG	PNG	M, A	NGO & gov.	Hab. &/or special features, spag	-	10-50%	Proxy of port landing & distance to ports	Lock-out/in reserves & mining leases	Marxan	2,510,750	50,000,000 m² BLM	NA
2015	Van Wynsberge et al.	French Polynesia	M, A	Academic & gov.	Hab. map (no detail on level)	Quickbird satellite image (2.4m.)	Giant clam density	Vulnerability of giant clam (in situ measures) & fishing effort (interviews)	-	GIS Esri® ArcMap 10.1	Approx. 28	25; 2500; 10,000; 40,000; 160,000 m²; DDPU	NA
2016	Cheok et al.	Fiji & FSM	M	Academic	Reef classes (5 different levels)	Landsat 7 ETM + (30m.) MCRMP	30%	Uniform or variable	-	Marxan	24,439 (Fiji) 32,168 (FSM)	1,000,000 & 25,000,000 m²	NA
2016	Tulloch et al.	PNG	A	Academic	Coastal ecosyst. types (9) (coral reef+geomorphic distrib.)	Landsat 7i ETM+ (90m.) MCRMP	30%	Opp. costs (global artisanal fishing data & survey) & land runoff (model)	Constraints from oil palm agriculture, & indirect pollution	Marxan 2.4 modified to take into account uncertainty	-	- BLM	NA
2016	Weeks et al.	FSM	A	Academic	Coral reefs (9) sea grass (8), fishes' home ranges (12).	MCRMP seagrass surveys	30%	-	Assessment of efficiency of reserves	-	-	-	NA
2016	Wendt et al.	Fiji	M, A	Academic & local communities	Geomorphic, benthic, hab., spag, turtle nesting & cultural sites	Field surveys & satellite imagery	30-80%	Opportunity cost, disputed areas, & enforceability	LMMA	Marxan with zones	446	15,000 m² BLM	LMMA: 12% reef protected, vs 19% for SCP discussed with comm.
2017	Hamel et al.	PNG	M, A	Academic	Geomorphic hab. (28)	Worldview satellite image (2m.)	20%	Fishing activity (7 proxies either validated by	-	Marxan	40	90,000 m²	Perceived fishing value: larger costs

								interviews or derived from the perceived fishing importance)					(4.5-14.4%) vs fishing activity (0.1-0.2%).
2017	Tulloch et al.	Fiji	M	Academic	Geomorphic (9) Benthic (33)	Quickbird (2.4m.), field surveys (Knudby et al, 2011)	30%	Equal cost or fishing opportunity cost (model)	Ignored existing MPA	Marxan or Marxan with Probability	262	5000 m²	NA
2017	Weeks	FSM	M, A	Academic	Nearshore marine hab. & mangroves	-	30%	Equal cost or combined seascape connectivity	-	Marxan	-	25,000 m²; BLM	NA
2018	Kabbadj et al.	French Polynesia	M, A	Academic & gov.	Overall biomass of clams, leagally exploited clams, abundance of recruits, area of hab. with highest density (4).	Combination of satellite imagery for habitat maps, & field work	10-30-50%	homogenous cost, fishing frequentation surrogate, distance to the closest *hoa*	Reserve & mass mortality events	QMarxanZ plugin in QGIS Wien 2.8.6.	-	250,000 m² (hexagon)	NA
2019	Oyafuzo et al.	Hawaii	M, A	Academic	Habitat-base distribution map for 7 bottom fish species (no precision).	-	Max. cons. value, reserve aggreg.; min. opp. cost, total reserve area.	Opportunity cost (gross revenue for 7 bottomfish)	Existing reserves	Marxan	1188	250,000 m² BLM	NA
2018	Delevaux et al.	Fiji	M, A	Academic	Hab., bathymetry, benthic group of corals (4) & fish group biomass (4)	Quickbird, Ikonos & Landsat Thematic Mapper +local coral reef survey	-	-	-	R with dismo & raster packages	-	3600 m²	NA
2019	Chung et al.	Hawaii	M, A	Academic	Hab. (11), Critical areas (5), Climate (2)	NOAA	5-100%	Proxy for herbivorous catch	Existing reserves, locked in or not	Marxan with Prob (5 features)	6565	650,000 m² (hexagon) BLM	NA
2019	Tsang et al.	Hawaii	M, A	Academic	3 features: total length of perennial stream; native vegetation	National Land Cover Dataset	15%	Proxy: habitat condition index (27 veriables)	-	Marxan	16,008	100,000 to 660,000,000 (irregular, DDPU by	NA

	cover; metric of inland-marine connectivity		drainage areas) BLM

*Table 4. **Technical and thematical recommendations** emerging from the analysis of the POTI SCP literature.*

Scenario for islands

1. Promote the assessment and implementation of simple SCP scenario, not only complex scenario

Sensitivity analysis

2. Perform sensitivity analysis to representation conservation targets, to counteract the arbitrary levels of representation frequently used in SCP
3. Conduct systematic sensitivity analysis of SCP solutions to the key parameters (habitat map characteristics, biodiversity inventories, PU size, etc.)

Data quality

4. Promote and fund collection of relevant data to limit the use of proxies, or at least to validate them

Documentation

5. Improve documentation on i) the parameterization and set-up of SCP software options used; ii) the results of sensitivity analysis.

Fishery

6. Promote and fund fishery atlases to better define fishery-related opportunity costs and fishery-related conservation objectives
7. Consider invertebrate resources, not only fish, for fishery based objectives or costs

Costs

8. Define and map opportunity costs beyond just fishers, including islanders' socio-cultural value and islanders' range of economic activity in particular mariculture and tourism
9. Collaborate with local or national managers to determine these objectives and costs

Integration of complex processes, with adequate data

10. Consider ridge to reefs approaches to include land-based criteria (threats, assets, costs, etc.) relevant for marine protection
11. Promote and implement connectivity and resilience concepts, with adequate data acquisition, including, but not limiting to genetic data
12. Use adequate downscaling techniques to infer island vulnerability to climate change

Scaling up networks

13. Scale-up conservation networks by taking into account customary reserves, while enhancing their ecological performances

Adaptive planning

14. 'Plan for new plans', with adaptive planning strategies

Supplementary Material SM1a.

Table SM1a. For each SCP POTI case study, the main questions, themes, specifics and take-home messages are developed.

Date	Authors	Region or country	Main questions, themes or take-home messages
2003	The Nature Conservancy	FSM	- Ecoregional assessment, as a foundation for conservation planning - Expert-driven identification of conservation targets and goals (terrestrial and marine)
2007	Hinchey et al.	Palau	- Ecoregional assessment, as a foundation for conservation planning - Expert-driven identification of conservation targets and goals (terrestrial and marine) - Iterative proposition of protected area networks using existing data, gap analysis, systematic conservation planning (SCP) concept, ridge-to-reef approach, and Marxan software as a tool
2008	Reimaanlok Nat'l Planning Team	Marshall Isl.	- Development of a national framework for the planning and establishment of community-based conservation areas - Expert-driven identification of conservation targets and goals (terrestrial and marine), and conservation gap analysis - Planning steps for implementation of action and community based fishery management
2009	Andréfouët et al.	Wallis	- MPA selection based on habitat representation (30%) and taking into account habitat map errors - Sensitivity to planning unit (PU) sizes - Surrogacy analysis between habitat and biological species, based on multi-taxa inventory
2009	Green et al.	PNG	- Application of SCP under a resilient framework to identify MPAs - Based on biodiversity and socio-economic proxies
2010	Jupiter et al.	Fiji	- First stages of conservation gap analysis to identify targets and goals
2010	Kool et al.	Solomon Isl.	- Gap analysis within a ridge to reef framework
2010	Lipsett-Moore et al.	Solomon Isl.	- Ridge to reef approach where conservation plans are proposed principally based on representation of habitats - Discuss the outcomes with a variety of stakeholders and traditional managers
2011	Adams et al.	Fiji	- Model opportunity costs and profits to fishers from their displacement due to conservation measures - Modelled opportunity costs and profits as a function of food fish abundance and probability of catch, based on gear type and market value of species - Fisher surveys provided catch per unit effort (CPUE) metrics and current fishing efforts - Compare various SCP scenarios with constraint on opportunity costs, profit or CPUE
2012	Klein et al.	Fiji	- Built on Klein et al. 2010. re-emphasize the importance of integrated land-reef planning for protection and prioritization - Assess how to maximize coral reef condition by minimizing land-based run-offs (itself a consequence of non-protection) - Reef condition is defined by an index of exposure to run-offs and fishing - Assess cost-effectiveness of protecting coral reefs when all forest is protected
2012	Mills et al.	Fiji	- Compare systematic vs ad hoc extension of MPA network in a 10 year period, in order to meet 2020 ecosystem representation targets - Ad hoc scheme emulated the Locally Managed Marine Area (LMMA) Fiji network expansion rates - Model the suitability of PU to become new MPA with Maxent software and various indicators - Suitability used as cost in the systematic approach

2013	Hamel et al.	Wallis and Futuna	- Assess how do fishery opportunity cost modulate habitat-based marine reserve plan - Assess how the thematic richness of habitat maps influence the planning outputs - Conclude on difficulty to use international guidelines for local implementation of marine reserves
2013	Makino et al. (a)	Fiji	- Test how zones (no-take, partially open, open), their effectiveness, and their costs, influence SCP solutions - Effectiveness is an *a priori* relative contribution to conservation objectives - Use Marxan with Zones software
2013	Makino et al. (b)	Fiji	- Target coral reef conservation with the objective of prioritizing marine reserves close to catchments with high forest cover - Aim to maximize intact land–sea protected area connections and minimize land-based run-offs on coral reefs. - Compare designs that allow for no connectivity, adjacent connectivity in the sea, symmetric and asymmetric land–sea connectivity - Conclude that connectivity has a huge influence on the solutions computed for habitat representation objectives
2013	Tulloch et al.	Fiji	- Assess of influence of habitat mapping errors in SCP outputs, using Marxan vs Marxan with Probability - The conservation objectives were defined by habitat representation levels (10-90%)
2013	Weeks and Jupiter	Fiji	- Propose one framework for adaptive management and conservation in time - Adaptive management required to enhance effectiveness of existing MPAs and improve resilience to climate change - Build on historical LMMA and their actions: customary, periodically harvested closures or permanent no-take areas - Use SCP tools under resilience framework - Identify factors affecting successful adaptive co-management
2014	Deas et al.	New Caledonia	- Assess how fishery opportunity costs modulate habitat-based marine reserve plan - Assess how the thematic richness of habitat maps influence the planning results - Assess how the type of opportunity cost influence the planning outputs- Discuss the value of using proxies - Provide practical guidelines for managers
2014	Klein et al.	Fiji	- Expand Klein et al. 2012 - Determine the incidental benefit of different terrestrial reserve networks to the condition of adjacent coral reefs - Assess how to maximize coral reef condition through investment in terrestrial protected areas - Compare results from the different prioritization approaches for land conservation - Recommend SCP, based on quantitative criteria (representation, adequacy, efficiency, complementarity) - Provide practical guidelines for managers
2014	Mills et al.	Solomon Isl.	- Use of social connectivity alongside ecological data in SCP exercise - Comparison of outputs when costs included social network - Integration of different levels of stakeholders facilitate potential scaling-up
2015	Gurney et al.	Fiji	- Influence of socio-economic factors on SCP outputs - Socioeconomic factors are treated as costs or objectives, stakeholders are treated as a single group or multiple groups - Equity is enhanced when multiple stakeholders are taken into account
2015	Government of PNG	PNG	- Identification of marine high conservation interest based on comprehensiveness, adequacy, representation and resilience (CARR) principles - Include definition of conservation objectives and goals, and gap analysis - Cost socio-economic proxy based on port landing data and distance from port - Use Marxan to identify high priority areas - Lead to proposals for regional analyses
2015	Van Wynsberge et al.	French Polynesia	- Assess what is the trade-off between PU size, data redundancy and data loss when designing MPA network - Provide practical guidelines for managers
2016	Cheok et al.	Fiji	- Assess the combined effects of size of PUs, habitat resolution and description on regional SC plans - Use simple (uniform and distance-based) proxies as socio-economic costs

			- Assess the incidental representation of conservation objectives between scenarios at different resolutions - Provide practical guidelines for managers
2016	Tulloch et al.	PNG	- Integrated land-marine planning exercise, in anticipation of development of oil palm plantations next to coral reefs - Assess the impact on coral reefs of various land-use development scenarios using a variety of biophysical models - SCP scenario targets habitat representation (30%), minimize fishers opportunity costs and maximize reefs in good condition (low sediment run-off impacts)
2016	Weeks et al.	FSM	- Discuss how to include fish movement knowledge in conservation prioritization - Discuss value of the consultation of stakeholders - Highlight the importance of understanding how MPAs are connected by larval dispersal, juvenile and adult movement (species dependency)
2016	Wendt et al.	Fiji	- Critically assess the value of SCP for management in a customary marine tenure context - Redesign with SCP principles a MPA network from an existing network - Conclude that benefits are indirect, through identifying and conceptualizing management issues, and in engaging communities for data collection and decision-making - SCP analytical solutions are of secondary importance
2017	Tulloch et al.	Fiji	- Evaluate the relative influence on SCP solutions and their costs when using habitat map with different resolution, accuracy and creation costs - Use Marxan with Probability to account for habitat map accuracy - Use fisher opportunity costs modeled in Adams et al. 2011
2017	Weeks	FSM	- Aim to include fish post-settlement connectivity in SCP prioritization algorithms - Target the inclusion of functionalities between habitat patches and not just their representation - In practice, a distance-based algorithm leads to connectivity metrics between adult and juvenile habitat patches - Connectivity metric is used as a cost function in Marxan
2018	Hamel et al.	PNG	- Assess what is the influence of proxies or of fishing data in minimizing lost fishing opportunities - Cross-compare the incidental costs induced by the use of different proxies - Focus on the perceived values of fishing grounds by local communities - Conclude that perceived value can be negatively impacted by proxies traditionally used in SCP
2018	Kabbadj et al.	French Polynesia	- Compare locally and regionally designed SC plans for giant clam population conservation - The threat is assumed to be principally climate-driven, not fishery-driven - Use different objectives derived from stock assessment data - Highlight the incidental effect of regional plans, in particular the resulting poor equity between sites - Provide practical guidelines for managers
2018	Delevaux et al.	Fiji	- Modeling framework to inform ridge to reef management
2019	Oyafuzo et al.	Hawai'i	- Assess with SCP tools the effectiveness of existing MPAs using opportunity cost metrics - Compare 3 opportunity cost scenarios and show that existing MPAs actually maximized opportunity costs - Recommend multiple-criteria decision making (MCDM) framework to assist reserve design
2019	Chung et al.	Hawaii	- Use herbivore spatial management to build reef resilience - Integrate climate change data
2019	Tsang et al.	Hawaii	- Integrate connectivity between terrestrial, freshwater and marine realms - Use Habitat Condition Index as a cost

Supplementary Material SM1b.

Table SM1b. Examples of SCP papers outside the POTI region but thematically of interest for POTIs. The main questions, themes or take-home messages are developed.

Date	Authors	Region or country	Main questions, themes or take-home messages
2005	Babcock et al.	General	- Review single-species models that have been used to model spatial zoning, including for MPAs - Ecosystem- based fishery management (EBFM) indicators are numerous, but few include a spatial component
2005	Stewart and Possingham	General	- The success of reserve proposals is often weighed against socio-economic criteria
2009	Ban et al.	Philippines	- Explore simple SCP scenarios that can be run with limited data (habitat or socio-economy), according to (or not) existing MPAs - Most sites worldwide, especially developing countries will be data limited - Socio-economic data are more critical than biophysical data to move forward with local communities in a data poor context
2010	Bartlett et al.	Vanuatu	- Call for more integration of local custom and culture to manage resources
2010	Klein et al.	Coral Triangle	- Emphasize the value of integrated land-reef planning to mitigate threats to coral reefs - Model at ecoregional scale management and opportunity costs associated with land and marine protected areas - Model the return of investment in terms of coral reef protection, which set priorities for managers
2010	Mills et al.	Coral Triangle	- Provide a comprehensive review of decisions about spatial scale that influence conservation planning outcomes - Understanding decisions about scale and related trade-offs can improve local conservation from regional plans & implementation of ecologically functional networks
2010	Weeks et al. (a)	Philippines	- Assess how to define opportunity cost where no socio-economic data is available in a small-scale fishery context - Assess the effectiveness of various socio-economic surrogates (area, population, coastal density, fishers, boats) - Conclude that surrogates based on the number of fishers or boats outperformed those based on overall population census data - Conclude that quality of socioeconomic data can be improved faster than biodiversity data, and can significantly impact conservation plans
2010	Weeks et al. (b)	Philippines	- Describe how to consider local marine tenure explicitly in SCP designs, in order to consider local objectives within a larger design - Use Marxan with Zones software with biodiversity/habitat and local fishing targets (minimize loss of fishing grounds) - Conclude that including local tenures boundaries, instead of considering all communities as one group, lead to larger costs but likely better socio-economic equity and acceptability - Suggest that there may be a tradeoff between the socioeconomic acceptability of shared costs and ecological viability of many small no-take areas
2011	Baker et al.	Marshall Isl.	- Formalize the development of a national framework for the planning and establishment of community-based conservation areas (cf. Reimaanlok National planning team, 2008) - Use SCP concepts, combined with indigenous knowledge, in a so-called hybrid plan
2011	Ban et al.	General	- Review how to design, implement and manage MPAs for coral reefs - In terms of SCP designs, identify emerging trends: more mixed bottom-up & top-down approaches; more use of socio-economic data; call for adaptive planning
2011	Game et al.	Solomon Isl.	- Develop a planning process using community-driven conservation opportunities, with a SCP approach to prioritization - The software Zonae Cogito, representing Marxan outputs, is used to facilitate exchanges with local communities

2011	Mills et al.	Fiji	- Conservation gap analysis with different scenario of effectiveness of existing protected areas - Assess how existing conservation areas meet the 2020 ecosystem representation objectives
2012	Allnutt et al.	Madagascar	- Critical assessment of prioritization methods at regional scale, including SCP methods - Use a variety of habitat, biodiversity, climate stress, and socio-economic proxies - Conclude that categorical methods can match the SCP optimization methods results - Conclude on the necessity to compare different method outputs
2012	Fernandes et al.	Coral Triangle	- Principles for trans-boundary designs with 3 objectives: fishery sustainability, biodiversity conservation, resilience to climate change - Focus on and enumerate biophysical principles; provide rationales
2012	Bottrill and Pressey	General	- Importance of effectiveness and evaluation for effective, adaptive, and informative conservation planning
2012	Hamel and Andréfouët	Maldives	- MPA selection based on biological species (multi-taxa) representation - Species distribution are generalized using habitat distribution, from different types of habitat maps - Solutions appear compatible with other approaches based on mega-fauna hot-spot and tourism activities
2012	Keppel et al.	Pacific Isl.	- Terrestrial focus but applicable to marine conservation - State that conservation is far from reaching its objectives for Pacific Islands Countries (PICS) - Highlight the problem of strong differences of approaches between governments and local NGOs, and international often well-funded big international nongovernment organizations (BINGOs) and donors - Suggest that current theory and practice for conservation is not entirely applicable to PICS considering social practice and values, in particular local customary resource management - Highlight that landowners should be key stakeholders in all conservation activities - Provide guidelines to improve efficiency and productivity of conservation programs in PICS
2012	Syakur et al.	Indonesia	- Combined approach from participatory and systematic conservation planning - Integration of local knowledge as costs - Local stakeholders, governments and international NGOs involved
2013	Grantham et al.	Indonesia	- Comparison of MPA from scoring and from prioritization - Use of local knowledge - Integration of fishing grounds and local tenure in costs and objectives, to improve equity - Costs are modelised by mariculture, fishing structures, fishing grounds and sediment plume
2013	Levy and Ban.	Coral Triangle	- Suggest ways to integrate Climate Change projections into SCP designs - Use spatial and temporal historical pattern of Sea Surface Temperature (SST) vs SST projection given by only one climate model - Targets projected areas less affected by climatic stress, within a temporal scheme, stratified by ecoregion - Study driven by coral bleaching information
2013	Torres-Pulliza et al.	Indonesia	- Identify reserve areas based on seagrass maps at ecoregion scale using a resilience framework - Demonstrate the value of updated habitat maps
2014	Andréfouët and Hamel	Solomon Isl.	- Using habitat maps at regional scale to systematically guide data gap analysis - Use inventory of meta-data
2014	Klein et al.	Fiji	- In a terrestrial island context, recommend decision makers to use prioritization approach and avoid additive scoring systems - Point out scoring systems main weaknesses: (i) could not achieve representation goals, (ii) use arbitrary weights for the selection criteria
2014	Makino et al.	Japan	- SCP motivated by temporal shift of coral species distribution due to global warming - Conservation objectives are temperature zones, not coral distribution zones - PU are defined by both a spatial and temporal index - Spatial and temporal connections between PU are modeled and taken into account by Marxan

			- Consider areas consistently important through time, and those temporary important - Planning according to future conditions was marginally more costly than planning for present conditions
2015	Horigue et al.	Philippines	- Comparing the efficiency of coordinated vs non-coordinated, and systematic vs non-systematic MPA designs across spatial scales and level of governance - Simulate the expansion of an existing network through different scenarios - Confirm the value of systematic planning when scaling-up MPA designs
2015	Maina et al.	Kenya	- Update coral reef habitat maps at national scales before computing various systematic conservation (SC) plans - Include a factor to minimize or maximize exposure to climate stressors - Compare the effects of different socio-economic proxies and costs - Conclude on the value of updating habitat maps and highlight the portfolio of possible solutions
2015	Makino et al.	Japan	- Follow-up of Makino et al. 2014 using different climate scenarios
2015	Mills et al.	Fiji and others	- Review on adaptive planning - Relevant case studies suggest that challenges are far from being all overcome - Challenges includes identification of triggers for change, several institutional limits, data gaps, and methods
2017	Cheok et al.	Fiji	- Focus on how regional scale designs translate into local actions, and after their implementation, discuss the adequate frequency of revisiting the designs - At each iteration, the network is expanded based on complementarity habitat (geomorphology) and rarity representation criteria - Evaluate time to reach final objectives, costs, and overlap between initial and final solutions
2017	Geange et al.	New Zealand	- Conservation gap analysis using Zonation SCP software - Compare existing MPA networks with SC plans designed to meet international representation guidelines
2017	Magris et al.	Brazil	- Compare existing set of MPAs and new clean-slate designs to assess cost-effectiveness for multiple coral reef conservation objectives - Consider objectives for biodiversity, connectivity, and resilience to global warming
2017	Pressey et al.	General	- Criticize on-going conservation actions based more on beliefs than on facts, and promote instead evidenced-based actions
2017	Jupiter et al.	Fiji, PNG, Solomon lsl., Hawaii	- Framework for Integrated Land-Sea Management (ILSM)
2018	Álvarez-Romero et al.	General	- Global review on SCP, with 155 studies - Create a database on SCP studies worldwide
2018	Jones et al.	Western Indian Ocean	- Identify priority fishery management area at regional scale, with different objectives and SCP prioritizing scenarios - Objectives are to minimize lost fishing opportunity, minimize recovery time of fish biomass, avoid areas of weak management and incorporate international collaboration - Solutions differ substantially between scenarios - Several objectives biased priority zones towards developed, wealthy and sparsely populated areas
2018	Sinclair et al.	General	- Survey of how practitioners, mostly academics, have used SCP - Responses biased towards developed countries - Clearly identify i) research studies and ii) studies aiming for real-word implementation - Conclude that collaboration will bridge gaps and that transfer from research to implementation is effective
2018	Weeks and Adams	Pacific Isl.	- List scientific questions that, if resolved, could help better management and conservation in small-island developing states (SIDS) - Sort priorities for academics, NGOs and government agencies - Emphasize the importance of involving a variety of practitioners and stakeholders to identify conservation and research priorities - Discuss the perception on the amount of already established knowledge useful for conservation, resource management in Oceania's SIDS, and local capacity to implement management actions

2018	Delevaux et al.	Hawai'i	- Modeling framework to inform ridge-to-reef management in Hawai'i - Includes customary ridge-to-reef conservation practices
2019	Kininmonth et al.	Philippines	- Aim to evaluate the best strategy for the progressive implementation of a MPA network in time - Algorithms for extension are compared regarding their capacity to maximize a meta-population mean life-time - Algorithms use larval dispersal connectivity models and graph theory metrics
2019	Krueck et al.	Indonesia	- Make simple plans linked to implementation - Design modified and socially improved with local knowledge interactions - field surveys for assessing fish assemblages and live coral cover

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