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Society-based solutions to coral reef threats in french pacific territories.

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Abstract:

Here, we give an overview of coral reef situations in the pacific French territories in a context of global change (especially threats linked to global change). We first characterize the coral reefs in New Caledonia, French Polynesia and Wallis and Futuna, specifying their location and specificities, their vulnerability and threats they face. We also emphasize the economic and cultural reliance on coral reefs by local communities and other inhabitants. Secondly, taking into account the natural and anthropogenic threats on coral reefs in the French pacific territories, we discuss the ecological solutions to environmental change, focusing on mitigation and adaptation strategies. Finally, we propose some socio-economic solutions for the region at different scales, with a special focus on enforcement measures and socio-political issues.

Keyword: Coral reef, French territories, Pacific, acidification, local communities, adaptation, mitigation

I Characteristics of coral reefs in the French pacific territories

I.1 Their localization and specificities

The French Pacific Islands are a complex and diverse ensemble of territories throughout the Central and South Pacific. Generalizing the potential effects of natural threats over such large scales and contrasting seascapes is thus particularly challenging. French Polynesia extends over approximately 5,000,000 km² of ocean. It is delimited by Motu One (7°50' S), Rapa (27°36' S), Temoe (134°28'W) and Scilly (154°40' W). It represents almost half of France’s EEZ, making it the largest EEZ behind the USA. The 120 islands are located in a general NW-SE orientation along 5 distinct archipelagos. Most of Islands are volcanic and a very large number are atolls (25% of all atolls worldwide). Emergent lands are about 3,500 km² and there is about 15,000 km² of lagoon. The population is of 281,674 (Insee-Ispf, RGS, 2017). New Caledonia has one main island of 19,100 km² surrounded by a 1,500 km long

barrier reef and a EEZ of 1,740,000 km². The reef encloses a lagoon of 24,000 km², up to 30 km distant from the shore. Five large Islands (<1,200 km²) are present on the east and south coasts and several far, pristine reefs are present in the north. The archipelago comprises numerous little islands and coral reefs, including fringing reefs, barrier reefs, atolls, uplifted reefs, and drowned reefs. The population is of 280 460 (Isee 2017). Wallis and Futuna are composed of two main archipelagos distant 230 km apart. Wallis is surrounded by a lagoon of around 60 km² while there is no lagoon around Futuna. The population is 11,562 inhabitants (Stsee, 2018). There are more Wallisian and Futunian, around 17000, living in New Caledonia than in their islands.

The regional specificities of those territories are characterized by a strong institutional and economic links with metropolitan France; a heterogeneity in biodiversity patterns; a mix of atolls and high islands. Coral reefs are exceptionally healthy and far from local pollution sources (GCRMN 2018)¹. There are various degrees of interconnection between people and coral reefs and a wide range of anthropogenic pressures, but less than in other coral reef areas.

I.2 Vulnerability and threats

Coral reefs are threatened by various types of local and large-scale anthropogenic and natural disturbances that cause widespread mortalities of reef building corals (scleractinian corals), the primary framework builders and key components of reef health and biodiversity. Main threats identified in French Polynesia at the global scale are seawater temperature increase, crown of thorns starfish outbreaks and extreme climatic events/coastal hazards. For this region, ocean acidification, although not immediate, is an emerging threat which has not yet been documented in the field. Other threats occurring at a local scale include sedimentation, pollution, the impact of the tourism industry in some specific islands, and overfishing in some localized areas. Among these threats some of them will affect reef health such as coral massive bleaching events while others will lead to the direct habitat destruction and loss of biodiversity. Only events from 1980 until now are considered in the following paragraphs.

Seawater temperature increase and bleaching

Scleractinian corals rely on the mutualistic symbiosis between the animal, the coral, and their intracellular dinoflagellates (commonly called zooxanthellae). When corals are exposed to heat stress, this symbiotic relationship may break down and bleaching occurs. Coral bleaching is defined as the loss of the zooxanthellae, loss/degradation of pigments from zooxanthellae or a combination of both of these factors (Douglas, 2003). The animal partner may survive and the symbiosis recover over a period of weeks to months or alternatively, the animal may die. Heat stress that results in bleaching can be partly natural (El Niño phenomenon) and partly human-produced (global warming), since anthropogenic activities worldwide influence increases in seawater temperatures.

In French Polynesia, coral bleaching events have been observed in 1983, 1987, 1991, 1994, 2002, 2003, 2007 (Adjeroud et al, 2018). Despite large decline in coral reef cover after bleaching events (as high as about 50 % in 1991), coral cover recovered to pre-disturbance levels very rapidly (Adjeroud, 2018). It is noteworthy that the greatest rates of coral loss was recorded during bleaching years (1991 and 2007) that coincided with other disturbances (a cyclone and an outbreak of *Acanthaster planci*, respectively), whereas in all other years where

¹ <http://www.criobe.pf/recherche/gcrmn/>

only bleaching has been recorded, coral loss was negligible (Traçon et al, 2011; Lamy et al. 2016). It has also been observed that corals' susceptibility to bleaching can decrease after subsequent bleaching events. For example bleaching intensity in 2007 was significantly lower than in 2002, suggesting that corals are capable of acclimatization and/or adaptation (Penin et al, 2013). Finally the susceptibility of corals to bleaching depends on the species and thus consecutive bleaching events could produce a coral assemblage that is more resistant to ongoing ocean warming (Pratchett et al, 2013). Concerning 2016, El Niño created a distinctive signature in seawater temperature for Moorea, but it did not cause widespread coral bleaching or mortality (Edmunds 2017).

New Caledonia is located just north of the Tropic of Capricorn in the South West Pacific between Australia and the Vanuatu, therefore more sub-tropical than French Polynesia and with an important climatic influence of the South Pacific Convergence Zone (SPCZ) during austral summer. This particular geographic position confers to New Caledonia a strong seasonality with winter sea surface temperature (SST) between 23°C and 24°C and summer maxima around 27–28°C. New Caledonia is not strongly affected by El Niño episodes, but these nevertheless bring to New Caledonia a drier atmosphere, cooler sea, and rainfall falls below seasonal averages. The oceanic impacts remains relatively weak with sea surface temperature typically cooling by ~ 0.5–1 degrees during El Niño phases. The first moderate bleaching event was reported in 1996 although only few data and observations have been reported which suggest that the event was of limited amplitude. In contrast, during the third world massive coral bleaching event in 2016, two-thirds of the New Caledonian reefs were affected by unusually warm sea surface temperatures for several months in concomitance with higher UV levels (i.e., lower cloud coverage) and very low wind activity, the latter dominant during the austral period (Benzoni et al 2017). Approximately all the fringing reefs around the Grande Terre and most of the Îles Loyautés were impacted with a 90% of coral coverage being affected. However, most of the bleached corals completely recovered but scattered crown-of-thorns starfish outbreaks were reported in several areas causing high mortality.

Crown of thorns starfish outbreaks

Outbreaks of the crown-of-thorns (COT's) sea star, *Acanthaster planci*, are widely recognized as a major threat to coral reef ecosystems. This starfish is a coral-feeder ("corallivore" that eats coral tissues) and is found on tropical reefs across the planet, except in the Atlantic Ocean. Populations of *A. planci* commonly show cyclic oscillations between long periods of low-density with individuals scarcely distributed among large reef areas, and brief episodes of unsustainably high densities commonly termed 'outbreaks'. What causes outbreaks of COT'S is not fully understood, but one accepted hypothesis is that COTS outbreaks are mostly driven by phytoplankton availability linked to nutrient delivery from the land (Brodie et al, 2005). Warmer seawater temperature could also be an important driver promoting COTS outbreaks (Uthicke et al, 2015).

In Moorea, for instance, the last two *A. planci* outbreaks occurred in 1979 and 2006, respectively (Lamy et al., 2016). The 2006 outbreak impacted the fore reef all around the island (Kayal et al., 201; Lamy et al. 2015). This event led to an almost loss of all living corals. However, the effect of the coral loss did not transfer equally throughout the food chain with heterogeneity in transfers of biomasses (Lamy et al. 2015) and a recovery debt in the ecosystem once the living coral cover recovered (Dubois et al. 2019).

While crown of thorns starfish outbreaks have been more or less localised to isolated reefs in New Caledonia reefs so far, according to recent observations (<http://oreanet.ird.nc/index.php/8-articles/4-cartes>) the phenomenon starts to become a serious

danger as it was in the 2006 and 2009 in French Polynesia. The outbreaks observed cannot be clearly linked with warming or over fishing which are two important drivers. Like in French Polynesia, nutrient enrichment from land could be an other important driver, though not sufficiently documented in New-Caledonia.

Although *A. planci* outbreaks may be part of the natural evolution of the reef (they have been described as “cleaners of the reef”, creating open space for new recruits), the balance between the natural occurrence of these disturbances and their frequency within the context of global change remains fragile.

Extreme climatic events/coastal hazards

In almost all archipelagos of French Polynesia, historical tsunami run-up and inundations are very limited (Etienne et al, 2012). However tsunami is a major coastal hazard in the Marquesas Islands owing to their position in the centre of the Pacific Ocean and the absence of protective coral reefs.

Warmer oceans are likely to lead to more powerful cyclones. Cyclones randomly affect anything in their path, including reef coastlines exposed to the swells of the storm. Although they are brief disturbances, they have long-term impacts on coral reef since they damage the 3-dimensional framework of coral constructions (Harmelin-Vivien 1994), and can alter these structures down to a depth of 30 m (Mangubhai 2016). Cyclones represent the second type of major coastal hazard in French Polynesia, especially in the Austral archipelago where cyclone frequency is one event every 6–7 years (Larrue & Chiron 2010). They are usually restricted to the western part of the territory; however, cyclones do encounter favourable growth conditions during El Niño Southern Oscillation (ENSO) periods (Terry & Etienne 2010), and may affect the Society and Tuamotu islands. Contrary to tsunamis, cyclones are very rare in the Marquesas. Since the 1980's, three cyclones affected French Polynesia, in 1983, 1991, 2010 but French Polynesia has not been hit by any other cyclone since 2010. A high potential for recovery following cyclones, has also been observed for some coral species which have the capacity for asexual propagation (such as *Acropora* sp., Kayal et al, 2015).

Cyclonic swell is generated by cyclonic activity outside the French Polynesia territory. It is a well-known and recurrent hazard in French Polynesia but still poorly documented.

Sedimentation

Climatic factors, i.e. seasonal changes in the orientation and heights of swells and waves modulate the amount of water flowing into the lagoon, before being flushed out into the open ocean, entraining particles. In addition, the impacts of coastal development on reefs include indirect effects such as changes in sedimentation rates which can affect the health of reef organisms. Indeed increased sedimentation rates reduce available light needed for coral growth and survival and cause burial of coral colonies, especially in shallow lagoons. Despite a scarcity of data for French Polynesia, it's been observed that some coastal reef areas are subjected to severe sedimentation (Schrimm et al, 2002). In addition to seasonal variability, sedimentation also displays significant spatial variability among locations (depending on anthropogenic activity, Rouzé, 2015) and according to hydrodynamism (Schrimm et al, 2002).

Sedimentation in New Caledonia could be an important issue for the large lagoon and coral reefs. The mining activity strips soil and causes erosion, destabilizes slopes, and leads to the formation of sediment that causes sediment banks in river mouths, sedimentation in bays, and

increased turbidity in the lagoon. During the last few decades, an intense mining activity has been promoted for the sake of economic growth. Nevertheless, the ecological impact of the nickel mining industry has been limited on waterways and on the lagoon thanks to a better water management including drainage and earthworks. Although sedimentation due to mining activity is limited in general, there could be an indirect threat for marine organisms due to nickel ore processing. New Caledonia has three large factories. Among the three factories present in New Caledonia only the most recent, located in the South (Mont-Dore-Yaté) could have the largest impact on the marine ecosystem because it uses sulfuric acid for the mineral extraction. They discharge waste rich in nickel and manganese ($1200\text{--}1500\text{ m}^3\text{ h}^{-1}$) into the lagoon, which is regularly monitored by the authorities. However, the effect on the coral reef organisms is poorly appreciated.

Pollution (pesticides, herbicides, nutrient inputs)

Shallow near-shore and lagoonal coral reef habitats are the first areas to be impacted by land-based sources of pollutants. Herbicides have proven to be widespread in organisms (algae, fishes and macroinvertebrates) of inshore reefs from the various archipelagos of French Polynesia (Tahiti, Moorea, Fakarava) except in Gambier (Salvat et al, 2016). Major herbicides detected in Polynesian reef organisms are atrazine, simazine and alachlor (Salvat et al, 2016, Roche et al, 2011). Researches carried out on pesticides in the reefs biotas from the Society Islands in French Polynesia have shown up a diffuse and ubiquitous contamination of coral reefs communities by organochlorine insecticides (Roche et al, 2011). To our knowledge no specific report on the impacts of herbicides or pesticides on Polynesian scleractinian corals is available but it is known that they can induce coral bleaching (Jones et al, 1999) and the sensitivity of corals varies across life history stages (Negri et al, 2005, Markey et al, 2007).

The impact of nutrients on corals depends on the threshold levels above which coral reefs would become degraded and also on complex local factors (Fichez, 2005). In coral reef lagoons, as in most coastal zones, nutrients (phosphorus and nitrogen) are generally the main factors limiting primary production but in lagoons with significant oceanic water inputs nitrogen is generally the essential limiting factor. In French Polynesia, in the most populated islands, waste water discharge and nutrient inputs are considered a major threats (Rapport IFRECOR, 2016 which favour algal growth and phytoplankton blooms. These algae are in direct competition with corals and are thus detrimental. However literature specific to French Polynesia and impacts on nutrients inputs on corals is scarce. New Caledonia has a relatively scarce human occupation of the land, and relatively moderate urbanisms, with the exception of the area in the proximity of the main city, Noumea. Despite significant efforts to improve waste management and urban sewage treatment, they are still largely insufficient and less than 50% of the population in Nouméa are linked to the sewage treatment network. As an example, the main industrial zone (Ducos) has no collective treatment network and individual arrangements are often inefficient or non-existent. These lead to marine pollution, particularly in the proximity of Noumea

Tourism

Tourism damages corals through activities such as snorkelling, SCUBA diving, and sampling of corals for infrastructure constructions (resorts, roads). The impacts can be direct with physical damage (the branching corals being the most impacted (Juhasz, 2010)) or indirect through input of waste in seawater (cf paragraph above). Obviously, impacts occur in zones

which have the most developed infrastructure such as the Society Islands in French Polynesia and the south province of New Caledonia.

Overfishing

In French Polynesia, reef fishery activities are quite challenging to quantify because of the diversity of gears used, the lack of centralized access points or markets, the high participation rates of the population in the fishery, and the overlapping cultural and economic motivations to catch fish. Compounding this challenging diversity, we lack a basic understanding of the complex interplay between the cultural, subsistence, and commercial use of French Polynesian's reefs. In Moorea, for instance, Leenhardt et al. (2016) found an order of magnitude gap between estimates of fishery yield produced by catch monitoring methods (~ 2 t km⁻² year⁻¹) and estimates produced using consumption or participatory socioeconomic consumer surveys (~ 24 t km⁻² year⁻¹). Different attempts exist to indirectly assess fishing effort (Thiault et al. 2017) or how fisheries were affected by environmental change (Rassweiler et al. 2019). Several lines of evidence suggest reef resources may be overexploited and stakeholders have a

diversity of opinions as to whether trends in the stocks are a cause for concern (Leenhardt et al. 2016). The reefs, however, remain ecologically resilient. The relative health of the reef is striking given the socio-economic context. Moorea has a relatively high population density, a modern economic system linked into global flows of trade and travel, and the fishery has little remaining traditional or customary management.

Conclusions

After disturbances such as bleaching, COTs and cyclones, it has been observed that the reefs in the French Pacific can recover, rapidly, within a decade. However, recurrent disturbances have probably overwhelmed the capacity of competitive coral taxa for recovery, and have progressively pushed communities towards the predominance of opportunistic and stress-tolerant species. At Moorea, *Pocillopora* and *Porites* are thus clearly the contemporary and, most probably, future ecological 'winners', whereas *Acropora* and *Montipora* appear to be the 'losers' (Adjeroud et al 2018). Under disturbances, many reefs undergo phase shifts in their benthic communities, which classically involves the replacement of corals by fleshy macroalgae or other non-reef-building organisms. Resistance of Moorea's reefs to a transition to macroalgal dominance probably results from the high grazing pressure by herbivorous fish (parrotfishes), whose densities remain stable, or even increase, and which are considered well above those needed to prevent proliferation of macroalgae (Adjeroud, 2018). Recovery of coral populations following disturbances also relies on the arrival of newly settling larval recruits, as well as on the growth and propagation of surviving colonies (Adjeroud, 2018). Therefore, regarding the main current threats for coral reefs in the regions, coral reefs seems quite resilient (Lamy et al. 2016), suggesting that these ecosystems have not yet reached their upper threshold of tolerance and that, based on the recent episodic stress events, they are highly resilient. A recent report "The Status and Trends of Coral Reefs of the Pacific", published in September 2018 shows that the coral reefs of the Pacific including the French Pacific, like in other parts of the world, are changing. As a matter of fact, even after apparent recovery as suggested by live coral cover, some reefs can exhibit some hidden recover debt in terms of ecosystem functioning (Dubois et al. 2019). But the change at the regional level is often not reflected in observations made at the local level, as is true for acute stress events such as coral bleaching episodes and Crown-of-Thorns outbreaks.

II The economic and cultural reliance on coral reefs by local communities (coastal protection, fisheries, tourism,...)

II.1 Cultural reliance on coral reefs

For the Oceanians, marine topography was almost as important as terrestrial topography. It varies a lot from island to island. Most of the Pacific islanders lived on the littoral zones or in the lower valleys in the humid tropical zone of the island. The choice of these locations depended on different parameters: be at a reasonable walking distance from the sea; accessibility to fresh water, close to the main agricultural production sites or picking, a place protected from prevailing winds and swells.

Although the fact that Polynesians and Melanesians are considered good fishermen probably comes from a bias related to the first European observers who were themselves sailors, it must be admitted that fishing was probably the activity where the Maohi and the Kanak had developed a lot of their technicality. Fishing was all the more a leisure occupation, as it was a necessity for subsistence. Several archeological excavations and research provides early fishing sites. For example on the atoll of Napuka (Tuamotu) the study uncovered about one hundred different technics. An ethno-historical study showed fishermen's knowledge regarding cycle of subsistence fishing and about the environment (Conte 1985).

What is certain is that fishing is the activity in which the Maohi take the most pleasure, close to the Western categories of "sport". Fishing was not only a way of getting food, but also a distraction. The chiefs were passionate about fishing and some excelled with all sorts of techniques: reef fishing, shark fishing, angling, etc. (Ellis 1829: II, 290-291, Moerenhout 1836: II, 108).

Most of the emblematic fishes such as sharks, ills, whales, turtles are considered as a personified ancestor or god (in the case of the Polynesian). This involve that natural living are considered as members of the extended family. In the Polynesian tradition for example, the coral (the papa) is the foundation of the mythical world. The relation between human, animal and coral are therefore based on a genealogical link instead of a human-nature relationship (Rigo 2004, Torrente 2014).

Therefore, New Caledonia and French Polynesia have both strong cultural tradition in the environmental regulation of ressources. There are customary reserve in New-caledonia as well as a management plan about the lagoon since the new-caledonian lagoon was awarded patrimony of humankind by the Unesco label. In French Polynesia, traditional management of the lagoon appears as a rahui in many archipelagos. A rahui is a temporary ban placed on a territory or a resource in eastern Polynesia (Bambridge 2016). In some archipelagos, specific fish or shell species could be "rahui" (forbidden) as in some others, part of a lagoon could be rahui (no uses are admitted).

Some island and atoll also have a Unesco label (the island of Raiatea and the atolls of Fakarava), where there are many management plans for fisheries regulation, environmental protection and integrated management plan through the urban plan. There is no codified management plan for the lagoon of Wallis and Futuna that is still under a customary mode of tenure.

In both French Polynesia and New Caledonia territories, protection measures to preserve coral reef and fishing account for a large spectrum: from absolute ban to relative constraints according to fishing techniques or period of the year.

II.2 Economic reliance on coral reef ecosystem services

Ecosystem services are the benefits people obtain from ecosystems, and are thus a valuable policy tool to improve their use and management (MA, 2005). Ecosystem services include provisioning (the products obtained from ecosystems), regulating (the benefits obtained from the regulation of ecosystem processes), and cultural services (non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences) that directly affect people (TEEB, 2008). When valuing coral reef services, it is important to take into account the full range of ecosystem services delivered by these ecosystems including hence provisioning, but also regulating, and cultural services. Indeed, the Total Economic Value (TEV)² of the coral reefs' ecosystem services can be significantly higher than their economic values alone, linked to food provisioning or tourism, for instance (UNEP-WCMC, 2011 and Vegh *et al.* 2014).

We can identify the main ecosystem services of coral reef ecosystems, that is, a wide range of food, material for construction and ornamental, and medicinal products, amenity or reef-associated surplus value on real state (provisioning), flood/storm protection and erosion control (regulating), and recreation and tourism, aesthetics and spiritual importance, and education and research (cultural) (UNEP, 2006). Taking the economic value of these services provided by coral reefs and associated eco-systems into consideration, is a crucial step in the economic development policies of French Oversea Territories in the South Pacific (Pascal, 2010; Pascal *et al.*, 2015, Pascal *et al.*, 2016). This economic value shows that these services generate a value close to 0.9 billion EUR, yearly. This value is equivalent to the added value of the banking sector for all of the overseas territories combined. More than 250 million EUR is visible in the annual financial flows of the territories' economies via the added values of services provided by coastal tourism and fishing associated with coral ecosystems. They contribute directly up to 2%, on average, to the regional governments' GDP. Other services, such as protection against coastal flooding and carbon sequestration, are not taken into consideration in the economic statistics, although they do save countries high costs from the avoidance of damage and stocks of carbon dioxide respectively.

Coastal protection, fisheries, CO₂ sequestration and recreation and tourism values dominate when estimating the TEV of the full range of ecosystem services. Firstly, 480 million EUR is

² The TEV is the most widely used framework to identify and quantify the contribution of ecosystem services to human wellbeing (MA, 2005). It is composed by use values, option values (the value people place on a future ability to use the environment and thus the potential future benefits of goods and services), and non-use or intrinsic values (existence values, where the benefit results from knowledge that goods and service exist and will continue to exist, independently of any actual or prospective use by the individual; and bequest value, where the benefit is in ensuring that future generations will be able to inherit the same goods and services of the present generation).

the annual value of the coastal protection services. Coral ecosystems absorb a huge amount of swell energy from waves. By reducing the damage to coastal construction during flooding and other extreme meteorological events, they are an important source of savings. 50 000 households and 2 million square meter of hotel and public infrastructures benefit from these protection services. Secondly, 150 million EUR is the annual value of services provided by fisheries. Fishing services are tied to biomass production by the coral ecosystems. In addition to commercial fishing, one also often finds subsistence and recreational fishing, which represent an important revenue and protein complement for some households. It involves more than 10,000 professional fishermen who receive an income from this activity. Likewise, more than 80,000 households obtain additional income and protein important to their wellbeing.

Thirdly, 150 million EUR is the annual value of CO₂ sequestration services in the 3 territories (mainly New Caledonia). Mangroves and sea grass beds are carbon sinks capable of sequestering CO₂. Estimation of the value for these services is based on the price of the voluntary carbon credits market. Taken in its entirety, the 30,000 hectares of mangroves and 60,000 hectares of sea grass beds in the 3 territories sequester the equivalent of 2 million tons of CO₂ each year. In these ecosystems, the superficial underground already contains a carbon stock estimated at 67 millions tons. Fourthly, 110 million EUR is the annual value of the coastal tourism services tied to the scenic beauty and the presence of emblematic species. Coral reef ecosystem allows an economic activity based on the recreational use of the reefs in different ways: discovery excursions, diving, sailing, beach day, etc. Every year more than 300 thousand people use the overseas reefs in various recreational ways. They generate benefits for nearly 300 recreation service providers and produce more than 800 direct jobs. We estimate that more than 12,000 indirect jobs are related to these uses, in the hotel business, catering and transport.

The existence value and the bequest value are particularly relevant in the context of coral reefs services in the French Pacific islands. In the existence value, the benefit results from knowledge that goods and service exist and will continue to exist, independently of any actual or prospective use by the current generation, while in the bequest value the benefit is in ensuring that future generations will be able to inherit the same goods and services of the present generation. In the Polynesian tradition, for example, the coral is the foundation of the mythical world. Natural living are considered as members of the extended family. The TEV of the coral reef ecosystem, is the formulation in monetary terms of other values such as the social and ethical, some of which rely on the notion of collective wellbeing. Through a cost-benefit analysis, this integrated approach that accounts for the TEV of coral reef ecosystems facilitates the appraisal of the desirability of a given protection, conservation or restoration policy on coral reefs in the ocean.

Intrinsic or non-use values, that is, the values of existence such as the aesthetics and the spiritual importance, and the values for future generations, remain unreported, though. Indeed, they are mainly valued using stated and revealed valuation methods, which are subject to methodological challenges such as very large variances, and to data gaps that are very expensive to address since they are context dependent. Besides raising serious ethical

questions, this issue is particularly penalizing for the appraisal of policies in the continental shelf and the open ocean, for instance, for platform reefs, inhabited islets, and deep-sea or cold-water corals, since the latter rely on a much more limited range of ecosystem services than the near coast.

III Socio-ecological solution for the region

Among potential relevant, feasible solutions, we suggest here some which appear to be better tailored to the local and regional contexts. First, nature-based solutions need to be implemented. This include the establishment of marine protected areas (MPAs) and the restoration of degraded coral reefs. However, this still require more research. For instance, there is not yet enough small scale evidence to fully guide the establishment of an ecological network of connected MPAs that would protect climate change-resistant hotspots. At a local scale, the selection and breeding of locally resistant corals can be implemented. However, it is still difficult to prioritize sites where to do restoration and to scale-up coral gardens at regional scale. An other option would be to restore and protect native vegetation (mangroves and native vegetation on atolls) for CO₂ sequestration, decrease salinization of groundwater, coastal protection and to enrich soils.

As for human based solution are concerned, the tongian sociologist E. Hauofa (1993) noticed that what is common among oceanians, not only the French pacific territories, is that “we” share the same ocean that has obvious connectivity with all lagoons. As a matter of fact, according to E. Hau’ofa:

A Pacific islands regional identity means a Pacific Islander identity. But what or who is a Pacific Islander? The issue should not arise if we consider Oceania as comprising human beings with a common heritage and commitment, rather than as members of diverse nationalities and races. Oceania refers to a world of people connected to each other. (...) For my part, anyone who has lived in our region and is committed to Oceania, is an Oceanian. This view opens up the possibility of expanding Oceania progressively to cover larger areas and more peoples than is possible under the term Pacific Islands Region. (...). We have to search for appropriate names for common identities that are more accommodating, inclusive and flexible than what we have today. (1993: 36)

Therefore, Hau’ofa proposed that Oceanians may become the “custodians of the oceans” (Hau’ofa 1993:40, because of their common cultural heritage. At an other level, French Polynesia contributed to the development of educative managed protected areas in the Marquesas archipelago. The children at school have developed their own MPA and they contribute to the awareness about the good health of the reef. This idea has been integrated into the environment law in French polynesia. Therefore, taking into account the natural resilience of the reef in the French territories of the Pacific, and the positive dynamics around reef protection and sustainable use, the French Pacific island territories could be used as champions of climate change solution, including research on resilience, management actions, renewable energy, etc. As a matter of fact, for finding solutions to coral reef degradation, it is urgent to understand the complex interactions between people and natural environment. Regarding coral reef, we must consider sea level rise, extreme climatic events, pollution,

fishing but also welfare and livelihood of the community. Putting social-ecological science into practice is possible at the small scale of Polynesia island, so multi approaches can be integrated. A research conducted in Moorea (Thiault et al. 2018; 2018a) shows that it is interesting to study the interactions between social and ecological vulnerabilities at an island scale and consider changes over time. If low system vulnerability is the fundamental management objective, then it can be achieved via actions to (1) reduce exposure, (2) decrease sensitivity, (3) enhance adaptive capacity, or a combination of those. So this kind of framework can connect science and policy, and also identify scenarios which can be discuss with the population. Moreover, the promotion of traditional coastal management practices as well as hybrid form of management combining tradition and modernity, could be implemented for sustainable use of marine resources. The recent development of very large MPA in the French polynesian and New Caledonian territories, is also part of this dynamic even if we lack scientific evidence about the relation and the benefits between large and smaller MPA.

An other important trend being developed in the French pacific territories is the potential relocation of activities according to projected climate change impacts. For example, frequent swell that hit the north of the atoll determine a relocation of the activities in the south part of the atoll. Recent studies insist in integrating population, especially in low island, to this kind of public policy (Bambridge and Latouche 2016)

IV Conclusion

Taking into account the diversity of the situations over a very large scale across the Pacific ocean, we consider that all solutions need to account for local social-economic-ecological which include local worldviews and values and local social organizations. In this perspective, there is a need for monitoring to track trends in ecological, socio-economic and cultural sub-systems.

The knowledge system is also diverse. As a matter of fact, these territories did develop a dialogue between science and culture in order to increase the interactions between traditional and scientific knowledge systems (monitoring, fundamental research, etc). Not only participatory approaches and citizen science are encouraged, but some protection and regulations measures in New Caledonia and French Polynesia rely on traditional expertise in order to design marine protected areas, and conservation measures.

The development of participatory practices in environmental governance lies in two converging movements: claims for local knowledge recognition and a progressive redefinition of landscape-planning methodologies. The Convention on Biological Diversity is a turning point for the reconsideration of the role of indigenous community. Local knowledge are explored and some authors (Roué and Nakashima, 2002) have included other perspectives such as culture and history to ecological management. This new perspective adopts a more integrative and multidisciplinary approach. The dominant top-down planning models have proven their inefficiencies in environmental issues. On the contrary, in French Polynesia,

several examples try to allow indigenous people to participate to the discussion, as the PGEM of Moorea. Community-based research can be a tool for empowerment and capacity building, it also helps in developing the transmission of ecological knowledge to future generations. Citizen science can contribute to the management as a tool for data collection. We can imagine a joint work among researchers and fishermen to identify changes in coral reef.

V Bibliography

Adjeroud M, Kayal M, Iborra-Cantonnet C, Vercelloni J, Bosserelle P, Liao V, Chancerelle Y, Claudet J, Penin L (2018) Recovery of coral assemblages despite acute and recurrent disturbances on a South Central Pacific reef, *Scientific reports* 8: 9680

Adjeroud, M., Michonneau, F., Edmunds, P., Chancerelle, Y., De Loma, T., Penin, L., Thibaut, L., Vidal-Dupiol, J., Salvat, B., and Galzin, R., (2009) Recurrent disturbances, recovery trajectories, and resilience of coral assemblages on a South Central Pacific reef, *Coral Reefs*, Vol. 28, No. 3, pp. 775-780

Bambridge T. (Ed), 2016. *The Rahui: Legal pluralism in Polynesian traditional management of resources and territories*. Australian National University press.

Bambridge T. et Latouche J.-P. (éd) 2016., *Les atolls du Pacifique face au changement climatique. Une comparaison Tuamotu-Kiribati*. Editions Karthala.

Brodie J, Fabricius K, De'ath G, Okaji K., (2005) Are increased nutrient inputs responsible for more outbreaks of crown-of-thorns starfish? An appraisal of the evidence. *Marine Pollution Bulletin* 51(1-4): 266-78

Burkepile, D. E., and Hay, M. E. (2008) Herbivore species richness and feeding complementarily affect community structure and function on a coral reef, *Proceedings of the National Academy of Science USA*, 105: 16201-16206

Burkepile DE, Hay ME (2010) Impact of Herbivore Identity on Algal Succession and Coral Growth on a Caribbean Reef. *PLoS ONE* 5(1): e8963. doi:10.1371/journal.pone.0008963

Conte Eric (1985). « Recherches ethno-archéologiques sur l'exploitation du milieu marin à napuka (Tuamotu), *Journal des océanistes*, 80, 51-56.

Douglas AE (2003) Coral bleaching- how and why? *Marine Pollution Bulletin* 46: 385-392

Dubois M, Gascuel D, Coll M, Claudet J (2019). Recovery debts can be revealed by ecosystem network-based approaches. *Ecosystems*. <https://link.springer.com/article/10.1007/s10021-018-0294-5>

Edmunds PJ (2017) Unusually high coral recruitment during the 2016 El Niño in Mo'orea, French Polynesia. *Plos One* 12(10): e0185167.

Ellis William (1829) *Polynesian Researches*. 2 vol. 536 et 576 p. London: Fisher, Son and Jackson.

Etienne (2012) Marine inundation hazards in French Polynesia: geomorphic impacts of Tropical Cyclone Oli in February 2010. *Geological Society*, London, Special Publications, 361: 21-39

Faure G (1989) Degradation of coral reefs at Moorea Island (French Polynesia) by *Acanthaster planci*. *J Coastal Res* 5: 295-305

Fichez R., Adjeroud M., Bozec Y.-M., Breau L., Chancerelle Y., Chevillon C., Douillet P., Fernandez J.-M., Frouin P., Kulbicki M., Moreton B., Ouillon S., Payri C., Perez T., Sasal P., Thébault J. (2005) A review of selected indicators of particle, nutrient and metal inputs in coral reef lagoon systems. *Aquatic Living Resources*, 18, p. 125-147.

Harmelin-Vivien LM (1994) The Effects of Storms and Cyclones on Coral Reefs: A Review. *Journal of Coastal Research*, 12, 211-231

Hau'ofa E., 1993. "The ocean in us" in E. Waddel, V. Naidu and E. Hau'ofa (eds), Culture and sustainable development in the Pacific, School of Social and Economic Development, University of the South Pacific, Suva, Fiji, pp 32-43.

IFRECOR (2016) Etat des récifs coralliens et des écosystèmes associés des Outre-mer français en 2015, 168p.

ISEE 2014. Institut de la statistique et des études économiques de la Nouvelle-Calédonie. www.isee.nc

Jones, R., Kildea, T., and Hoegh-guldberg, O. (1999) PAM Chlorophyll Fluorometry: a new in situ technique for stress assessment in scleractinian corals, used to examine the effects of cyanide from cyanide fishing, *Marine Pollution Bulletin*, Vol. 38, No. 10, pp. 864-874

Juhasz A, Ho E, Bender E, Fong P (2010) Does use of tropical beaches by tourists and island residents result in damage to fringing coral reefs? A case study in Moorea French Polynesia. *Marine Pollution Bulletin* 60: 2251-2256

Kayal, M., Lenihan, H. S., Pau, C., Penin, L., and Adjeroud, M. (2011) Associational fuges among corals mediate impacts of a crown-of-thorns starfish *Acanthaster planci* outbreak Coral Reefs, Vol. 30, No. 3, pp. 827-837.

Kayal, M., Vercelloni, J., Lison de Loma, T., Bosserelle, P., Chancerelle, Y., Geoffroy, S., Stievenart, C., Michonneau, F., Penin, L., Planes, S., and Adjeroud, M. (2012) Predator crown-of-thorns starfish (*Acanthaster planci*) outbreak, mass mortality of corals, and cascading effects on reef fish and benthic communities. *PloS one*, Vol. 7, No. 10, p. e47363

Kayal, M., Vercelloni, J., Wand, M. P., Adjeroud, M. (2015) Searching for the best bet in life-strategy: A quantitative approach to individual performance and population dynamics in reef-building corals. *Ecol. Complex.* 23, 73–84

- Keesing JK, Lucas JS (1992) Field measurement of feeding and movement rates of the crown-of-thorns starfish *Acanthaster planci* (L.). *Journal of Experimental Marine Biology and Ecology* 156: 89-104.
- Lamy T, Galzin R, Kulbick M, Lison de Loma T, Claudet J (2016). Three decades of recurrent declines and recoveries in corals belie ongoing change in fish assemblages. *Coral Reefs* 35: 293-302.
- Lamy T, Legendre P, Chancerelle Y, Siu G, Claudet J (2015). Understanding the spatio-temporal response of coral reef fish communities to natural disturbances: Insights from beta-diversity decomposition. *PLoS ONE* 10: e0138696.
- Larrue S, Chiron T (2010) Les îles de Polynésie française face à l'aléa cyclonique, *Vertigo*, vol. 10, n° 3
- Leenhardt P, Lauer M, Madi Moussa R, Holbrook SJ, Rassweiler A, Schmitt RJ, Claudet J (2016). Complexities and uncertainties in transitioning small-scale coral reef fisheries. *Frontiers in Marine Science* 3:70.
- Mangubhai S (2016) Impact of Tropical Cyclone Winston on Coral Reefs in the Vatu-i-Ra Seascape. Report No. 01/16. Wildlife Conservation Society, Suva, Fiji. 27 pp.
- Markey KL, Baird AH, Humphrey C, Negri AP (2007) Insecticides and a fungicide affect multiple coral life stages. *Mar Ecol Prog Ser* 330: 127-137
- Millennium ecosystem assessment (MA), 2005. *Ecosystems and human well-being: General synthesis*. Island Press, Washington, DC.
- Moerenhout J. A. (1837) *Voyages aux îles du Grand Océan*. 2 vol. 1094 p. Paris: Adrien Maisonneuve.
- Moritz C, Vii J, Lee Long W, Tamelander J, Thomassin A, Planes S (editors). (2018) Status and Trends of Coral Reefs of the Pacific. Global Coral Reef Monitoring Network. 218 p.
- Negri A, Vollhardt C, Humphrey C, Heyward A, Jones R, Eaglesham G, Fabricius K (2005) Effects of the herbicide diuron on the early life history stages of coral. *Mar Pollut Bull* 51: 370-383
- Pascal N (2010) Ecosystèmes coralliens de Nouvelle-Calédonie, valeur économique des services écosystémiques Partie I: Valeur financière. IFRECOR (Initiative Française pour les Récifs Coralliens) Nouvelle-Calédonie, Nouméa, Avril 2010, 155 pp + 12 planches
- Pascal N, LePort G, Allenbach M (2015) Ecosystèmes coralliens de Polynésie Française, valeur économique des services écosystémiques - Partie I: Valeur financière. IFRECOR (Initiative Française pour les Récifs Coralliens), Juillet 2015, 202 p
- Pascal N, Leport G, Allenbach M, Marchand C (2016) Valeur économique des services rendus par les récifs coralliens et écosystèmes associés des Outre-mer français. Rapport technique pour l'Initiative Française pour les Récifs CORalliens (IFRECOR), 56 pages

Penin, L., Vidal-Dupiol, J., and Adjeroud, M. (2013) Response of coral assemblages to thermal stress: are bleaching intensity and spatial patterns consistent between events? *Environmental Monitoring and Assessment*, Vol. 185, No. 6, pp. 5031-5042

Pratchett MS, McCowan D, Maynard JA, Heron SF (2013) Changes in Bleaching Susceptibility among Corals Subject to Ocean Warming and Recurrent Bleaching in Moorea, French Polynesia. *PLoS ONE* 8(7): e70443. doi:10.1371/journal.pone.0070443

Rassweiler A, Lauer M, Lester SE, Holbrook SJ, Schmitt RJ, Moussa RM, Munsterman KS, Lenihan HS, Brooks AJ, Wencélius J, Claudet J (2019). Perceptions and responses of Pacific island fishers to changing coral reefs. *Ambio*.

Rigo B., 2004. *Altérité polynésienne et conscience occidentale*. Edition du CNRS, Paris.

Roche, H. R., Salvat, B. S., and Ramade, F. R. (2011) Assessment of the pesticide pollution of coral reef communities from French Polynesia, *Revue d'Ecologie*, Vol. 66, pp. 3-10

Roué and Nakashima, 2002. Des savoirs « traditionnels » pour évaluer les impacts environnementaux du développement moderne et occidental ». *Revue internationale des sciences sociales* 173(3). DOI: 10.3917/riss.173.0377

Rouzé H, Lecellier G, Langlade MJ, Planes S, Berteaux-Lecellier V (2015) Fringing reefs exposed to different levels of eutrophication and sedimentation can support similar benthic communities. *Marine Pollution Bulletin* 92: 212-221

Salvat B, Roche H, Ramade F (2016) On the occurrence of a widespread contamination by herbicides of coral reef biota in French Polynesia. *Environ Sci Pollut Res* 23:49-60

Schrimm, M., Heussner, S., and Buscail, R. (2002) Seasonal variations of downward particle fluxes in front of a reef pass (Moorea Island, French Polynesia), *Oceanologica Acta*, Vol. 25, No. 2, pp. 61-70

STSEE, Service territorial de la statistique et des études économiques de Wallis et Futuna. www.stsee.wf

Thiault L, Collin A, Chlous F, Gelcich S, Claudet J (2017). Combining participatory and socioeconomic approaches to map fishing effort in small-scale fisheries. *PLoS ONE* 12: e0176862.

Thiault L, Marshall P, Gelcich S, Chlous F, Claudet J (2018). Mapping social-ecological vulnerability to inform local decision making. *Conservation Biology* 32: 447-456.

Thiault L, Marshall P, Gelcich S, Collin A, Chlous F, Claudet J (2018a). Space and time matter in social-ecological vulnerability assessments. *Marine Policy* 88: 213-231.

Torrente Frédéric, 2014. *Buveurs de mer. Mangeurs de terres. Histoire des guerriers d'Anaa, atoll des Tuamotu*. Edition Te pito o te Fenua.

TEEB, 2008. *An interim report*. European Communities, Brussels, Belgium.

Terry, J. P. & Etienne, S (2010) Tempestuous times in the South Pacific islands. *Science*, 328, 5977, 428-429

Trapon, M. L., Pratchett, M. S., and Penin, L. (2011) “Comparative effects of different disturbances in coral reef habitats in Moorea, French Polynesia,” *Journal of Marine Biology*, Vol. 2011, Article ID 807625, pp. 1-11

UNEP, 2006. *Marine and coastal ecosystems and human wellbeing: A synthesis report based on the findings of the Millennium Ecosystem Assessment*. UNEP, 76pp.

Uthicke S, Logan M, Liddy M, Francis D, Hardy N, Lamare M (2015) Climate change as an unexpected co-factor promoting coral eating seastar (*Acanthaster planci*) outbreaks. *Scientific Reports* 5: 8402

UNEP-WCMC, 2011. “Marine and coastal ecosystem services: Valuation methods and their application”. UNEP-WCMC *Biodiversity Series* No. 33. 46 pp.