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

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A B S T R A C T

This article reviews the state of coral reefs in French Pacific territories in the context of global change (especially threats linked to climate change). We first outline the specific local characteristics, vulnerabilities, and threats faced by the coral reefs of New Caledonia, French Polynesia and Wallis and Futuna. We also emphasize local and other human communities' economic and cultural reliance on coral reefs. Secondly, we discuss the natural and anthropogenic threats facing coral reefs in French Pacific territories, and current ecological responses such as mitigation and adaptation strategies. We conclude by proposing socio-economic solutions for the Pacific region across varying scales, with a special focus on enforcement measures and socio-political issues.

1. Characteristics of coral reefs in French Pacific territories

1.1. Local diversity

The French Pacific Islands are a complex and diverse collection of island and marine environments spread across thousands of kilometers. Reviewing the potential effects of natural threats upon such large-scale and contrasting seascapes is particularly challenging. The French Pacific consists of three territories: French Polynesia in the southeast Pacific, New Caledonia in the southwest Pacific, and Wallis and Futuna in the central Pacific. French Polynesia extends over approximatively 5,000,000 km^2 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 Exclusive Economic Zone (EEZ), making it the second largest EEZ after that of the USA. It consists of 120 islands located in 5 distinct archipelagos with a general NW-SE orientation. Most of Islands are volcanic and a very large number are atolls (25% of all atolls worldwide). These islands comprise about 3500 km^2 of land surrounded by 15,000 km^2 of lagoon. The population numbers 281,674 (Ispf, 2017). New Caledonia has one main island of 19,100 km^2 surrounded by a 1500 km long barrier reef and an EEZ of 1,740,000 km^2. The reef, which up to 30 km distant from the shore in places, encloses a lagoon of 24,000 km^2. Five large islands with a combined landmass of over 1200 km^2 lie off the east and south coasts, while several pristine reefs are found further away to the north. The archipelago comprises numerous little islands and coral reefs, including fringing reefs, barrier reefs, atolls, uplifted reefs, and drowned reefs. The population numbers 280,460 (ISEE, 2014). The last territory is Wallis and Futuna which are 230 km apart. Wallis is surrounded by a lagoon of around 60 km^2 while there is no lagoon around Futuna. The combined resident population of the two is 11,562 inhabitants (STSEE, 2018), while around 17,000 Wallisians and Futunans live in New Caledonia.

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While all of these territories are characterized by strong institutional and economic links with metropolitan France, environmentally they contain a range of atolls and high islands with great biodiversity. Most of these territories' 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 in the French Pacific, and a wide range of anthropogenic pressures, but less than in other coral reef areas of the world.

1.2. Vulnerability and threats

Coral reefs are threatened by various types of local and large-scale anthropogenic and natural disturbances that cause widespread mortality to reef-building corals (scleractinian corals), the primary framework builders and key components of reef health and biodiversity. The main externally derived threats identified in French Polynesia are seawater temperature increase, crown of thorns starfish outbreaks, and extreme climatic events /coastal hazards. For this region, ocean acidification, although not a major immediate concern, 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. Some of these threats will affect reef health such as massive coral bleaching events, while others will lead to the direct habitat destruction and loss of biodiversity. The following discussion covers the period from 1980 until the present.

Seawater temperature increase and bleaching

Scleractinian corals rely on 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 a 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 were 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 only bleaching has been recorded, coral loss was negligible (Trapon et al., 2011; Lamy et al., 2016). It has also been observed that the susceptibility of corals' to bleaching can decrease during 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). The 2016 El Niño event 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 southwest Pacific between Australia and Vanuatu. It is therefore more sub-tropical than French Polynesia and is also distinguished by the climatic influence of the South Pacific Convergence Zone (SPCZ) during the austral summer. New Caledonia's particular geographic position conveys 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 below seasonal average rainfall. 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 in New Caledonia was reported in 1996. The few data and observations reported suggest that the event was of limited amplitude. In contrast, during the third massive global coral bleaching event in 2016, two-thirds of the New Caledonian reefs were affected by unusually warm sea surface temperatures for several months, combined 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 main island, Grande Terre, and most of the Îles Loyautés (Loyalty Islands) were impacted, with 90% of coral 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 "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 cyclical 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 foreshore reef all around the island (Kayal et al., 2011, 2012; Lamy et al., 2015). This event almost wiped out all living corals in the outbreak area. 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 COT's outbreaks have been more or less localized 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 is starting to become a serious danger in New Caledonia as it was in the 2006 and 2009 in French Polynesia. The outbreaks observed cannot be clearly linked to global warming or over fishing which are two important drivers. Although not sufficiently documented in New-Caledonia, nutrient enrichment from land runoff could be another important driver as is the case in French Polynesia. COT's have been described as "cleaners of the reef", creating open space for new recruits. However, although *A. planci* outbreaks may be part of the natural evolution of the reef, the balance between the natural occurrence of these

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

disturbances and their frequency within the context of global and local human-induced change remains fragile.

Extreme climatic events/coastal hazards

Natural hazards have not been historically prominent in most French Pacific territories. In almost all archipelagos of French Polynesia, for example, historical tsunami run-up and inundations are very limited (Etienne, 2012). However, tsunami are a major coastal hazard in the Marquesas Islands owing to their position in the center 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 storm swells. Although they are brief disturbances, they have long-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 and Chiron, 2010). They are usually restricted to the western part of the territory; however, cyclones do encounter favorable growth conditions during El Niño Southern Oscillation (ENSO) periods (Terry and Etienne, 2010), and may affect the Society and Tuamotu islands. Contrary to tsunamis, cyclones are very rare in the Marquesas. French Polynesia has been hit by three cyclones since 1980: in 1983, 1991, 2010. 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). More distant cyclones also occasionally have an impact on the French Pacific.

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. This ebb and flow of seawater entrains particles and affects sedimentation loads in reef–lagoon complexes. 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. Increased sedimentation rates reduce available light needed for coral growth and survival, and can even bury coral colonies, especially in shallow lagoons. Despite a scarcity of data for French Polynesia, it is 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 et al., 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, mining activity has intensified to promote 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 processing mining extractions. Among the three factories present in New Caledonia, the most recent, Mont-Dore-Yaté in the south of Grand Terre, (REMOVED ONLY) potentially poses the largest threat on the marine ecosystem because it uses sulfuric acid for mineral extraction. All three discharge waste rich in nickel and manganese (1200–1500 m^3 h^{-1}) into the lagoon, which is regularly monitored by the authorities. However, the effect on the coral reef organisms is still poorly understood.

Pollution (pesticides, herbicides, nutrient inputs)

Shallow near-shore and lagoon 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 the Gambier Archipelago (Salvat et al., 2016). The major herbicides detected in Polynesian reef organisms are atrazine, simazine and alachlor (Salvat et al., 2016; Roche et al., 2011). Research into pesticides in the reef 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. However, studies elsewhere demonstrate that they can induce coral bleaching (Jones et al., 1999) and that 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 become degraded and also on complex local factors (Fichez et al., 2005). In coral reef lagoons, as in most coastal zones, nutrients (phosphorus and nitrogen) are generally the main factors limiting primary production. However, in lagoons with significant oceanic water inputs nitrogen is generally the essential limiting factor. In most populated islands of French Polynesia, waste water discharge and nutrient inputs are considered to be major threats (Rapport IFRECOR, 2016) which favor algal growth and phytoplankton blooms. These algae are in direct competition with corals and thus detrimental to coral communities. However, literature specific to French Polynesia and impacts on nutrients inputs on corals is scarce. New Caledonia has a relatively low density human settlement, and relatively moderate urbanization, with the exception of the main city, Noumea, and its immediate surroundings. Despite significant efforts to improve waste management and urban sewage treatment, they are still largely inadequate as less than 50% of the population in Nouméa is connected to the sewage treatment network. For 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.

Other Human Activities Affecting Corals

Tourism damages on corals can occur through activities such as SCUBA diving and snorkelling when not properly organizedor regulated through exceeding carrying capacity, anchoring damage, and other unsustainable practices. Another 2 main categories of impacts includes (i) destruction of corals for infrastructure constructions (resorts, jetties, roads, boardwalks, etc.) (Juhasz et al., 2010) and (ii) water contamination through wastewater (cf paragraph above). The main impacts occur in zones which have the most developed infrastructure such as the Society Islands in French Polynesia and the southern province of New Caledonia where Noumea is located.

In French Polynesia, reef fishery activities are difficult to monitor and 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. This challenging plethora of monitoring difficulties is compounded by a basic lack of 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} $year^{-1}$). There have been a number of attempts 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 also that 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.

Section conclusions

It has been observed that the reefs in the French Pacific can recover, rapidly after disturbances such as bleaching, COTs and cyclones. Sometimes this recovery happens 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. The 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). At present, coral reefs seems quite resilient in the face of the main current threats they face in the French Pacific territories just outlined above (Lamy et al., 2016). This suggests 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. "The Status and Trends of Coral Reefs of the Pacific" report published in September 2018 shows that the coral reefs across the Pacific (including the French Pacific) are changing. The same is true for reefs beyond the Pacific. 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.

2. Coral reefs and local communities

2.1. Cultural reliance on, and relationships with coral reefs

Pacific Islanders are increasingly identifying themselves as 'Oceanians' in recognition of their special and intimate relationship with the sea. Throughout their history, marine topography has been almost as important to Oceanians[2] as terrestrial topography. It varies considerably from island to island. With the exception of the fertile and densely settled highlands of New Guinea, most Pacific Islanders/Oceanians lived on the littoral zones or in the lower valleys in the humid tropical zone of their islands. The choice of these locations depended on different parameters: being at a reasonable walking distance from the sea; accessibility to fresh water, close to the main agricultural production sites, or selecting a place protected from prevailing winds and swells.

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. However, there is also considerable evidence that fishing was probably the activity where the Maohi and the Kanak, the indigenous people of the Society Islands and New Caledonia respectively, developed some of their most sophisticated proficiency. Fishing was as much a leisure occupation as it was a necessity for subsistence. Several archeological excavations and research provides early fishing sites. For example, a study of the atoll of Napuka in the Tuamotu Archipelago uncovered about one hundred different fishing techniques. An ethno-historical study revealed fishermen's detailed and sophisticated knowledge regarding the cycle of subsistence fishing and about the environment (Conte, 1985). 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 favored activity. 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, 1837: II, 108).

The marine world was not only deeply embedded in Oceanian activities. It was also an intimate part of their identity and ancestry and resulted in a strong commitment to protecting the marine environment. In Polynesia, most of the emblematic fishes such as sharks, ills?, whales, and turtles are considered as a personified ancestor or god. These marine species were 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 dichotomous relationship (Rigo, 2004; Torrente, 2014). It is therefore not surprising that New Caledonia and French Polynesia have both strong cultural tradition in the environmental regulation of resources. There are customary reserves in New Caledonia as well as a management plan about the lagoon since the New Caledonian lagoon was awarded a UNESCO designation of patrimony of humankind. 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 archipelagoes, specific fish or shell species could be placed under a "rahui" which made them forbidden to harvest. At other times and in other circumstances, entire sections of a lagoon could be placed under rahui with no use of resources there allowed.

Some island and atoll also have a special UNESCO designation, such as the island of Raiatea and the atolls of Fakarava, where there are many management plans for fisheries regulation, environmental protection and integrated management plan within the urban plan. There is no codified management plan for the lagoon area of Wallis and Futuna which is still under a customary mode of tenure. In both French Polynesia and New Caledonian territories, protection measures to preserve coral reef and fishing embrace a large spectrum: from absolute ban to relative constraints according to fishing techniques or period of the year.

2.2. 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

[2] We discuss the origin and the relevance of the term "oceanian" in more detail in the last section.

and management (MEA, 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 across the entire provisioning, regulating, and cultural services spectrum. Indeed, the Total Economic Value (TEV)[3] of the coral reefs' ecosystem services can be significantly higher than their economic values alone, linked to food provisioning or tourism, for instance (UNEPWCMC, 2011 and Vegh et al. 2014).

The coral reef ecosystems covers a wide range of ecosystem services from food, material for construction and ornamentation, and medicinal products, 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 ecosystems into consideration is a crucial for the economic development policies of French Oversea Territories in the South Pacific (Pascal, 2010; Pascal et al., 2015, 2016). Focusing on the ecosystem services of protection against coastal flooding, fish biomass, scenic beauty and carbon sequestration, economic valuation shows that the coral reef ecosystems generate a value close to 0.9 billion EUR, yearly (Pascal et al., 2015). To put this in economic perspective, this value is the equivalent to the added value of the banking sector for all of French 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 scenic beauty (coastal tourism) and fish biomass (commercial and subsistence) from fishing associated with coral ecosystems. They contribute up to 2% directly, 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 (e.g. GDP). This is a serious omission as they save countries high mitigation activity costs from the avoidance of physical damage and stocks of carbon dioxide respectively.

Coastal protection, fisheries, CO_2 sequestration, and recreation and tourism values dominate when estimating the TEV of the full range of ecosystem services (Pascal et al., 2015). Four aspects are involved. First, 480 million EUR is the annual value ascribed to coastal protection services (Pascal et al., 2016). 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 meters of hotel and public infrastructures benefit from these protection services. Secondly, 150 million EUR is the annual value of services provided by fisheries (Pascal et al., 2016). 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.

The third aspect is the 150 million EUR in annual value of CO_2 sequestration services in the 3 territories (mainly New Caledonia) (Pascal et al., 2016). Mangroves and sea grass beds are carbon sinks capable of sequestering CO_2. 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 sequestrate the equivalent of 2 million tons of CO_2 each year. These two ecosystems alone already contain a carbon stock estimated at 67 million tons.

The fourth and last element is the 110 million EUR is the annual value of the coastal tourism services tied to the scenic beauty and the presence of emblematic species (Pascal et al., 2016). Coral reef ecosystems allow economic activity based on the recreational use of the reefs in different ways: discovery excursions, diving, sailing, beach days, and so on. Every year more than 300,000 people use the overseas (meaning and location meant by 'overseas' unclear — do you mean French Pacific territory coral reefs?) 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 sectors.

The Œexistence value and the Œbequest value (TEEB, 2010) seem particularly relevant in the context of coral reef services in the French Pacific islands. Coral reefs existence value 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 lies in ensuring that future generations will be able to inherit the same goods and services of the present generation (Groot et al., 2002). As has already been noted above for example, coral is the foundation of the Polynesian mythical world. Natural living marine organisms are considered as members of the extended family.

The TEV (Total Economic Value), is the formulation in monetary terms of all values produced by the ecosystems. It is a common approach used in economic evaluation worldwide (Laurans et al., 2013) The TEV for coral reef includes use values (e.g. extractive and non-extractive values such as fishery or tourism added values) and non uses values (such as existence and bequest values). Specific methods for the valuation of non-uses values have been developed (revealed preferences, choice experiment, etc. (TEEB, 2010). The non-uses values rely on the notion of collective wellbeing. This integrated TEV approach facilitates the economic appraisal of the impacts of a given protection, conservation or restoration policy on coral reefs on many different services delivered by the ecosystems.

Intrinsic or non-use values such as aesthetic and the spiritual importance, and the values for future generations, remain unreported in most methods of measuring ecosystem value. 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 derive value from a much more limited range of ecosystem services than ecosystems closer to coastlines.

3 The TEV is the most widely used framework to identify and quantify the contribution of ecosystem services to human wellbeing (MEA, 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).

3. 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 of French Pacific territories. 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 for restoration and to scale-up coral gardens at a regional scale. Another option would be to restore and protect native vegetation (mangroves and native vegetation on atolls) for CO_2 sequestration, decreased salinization of groundwater, coastal protection and to enrich soils.

As for human based solution are concerned, the Tongan sociologist Epeli Hau'ofa (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 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 people 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 another level, French Polynesia has contributed to the development of educative managed protected areas in the Marquesas archipelago in ways that enhance inter-generational commitment to coral reef preservation. 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 coral reefs in the French Pacific territories, and the positive dynamics around reef protection and sustainable use, the French Pacific island territories could be used as champions of climate change solutions, including research on resilience, management actions, renewable energy and other inter-related solutions to environmental problems confronting the world's oceans.

These French Pacific initiatives have a wider importance and potential application. There is an urgent need to understand the complex interactions between people and their natural environments to ensure enduring and effective solutions to coral reef degradation. Regarding coral reefs, we must not only consider sea level rise, extreme climatic events, pollution, fishing but also the welfare and livelihood of local communities using the coral reefs. Putting social-ecological science into practice is especially possible in French Polynesia because of the small scale of Polynesian island communities which allows multiple approaches to be integrated (and tested?). Research conducted in Moorea (Thiault et al., 2018,a) revealed interesting interactions between social and ecological vulnerabilities at an island scale, and considerable 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 these three. This kind of framework can connect science and policy, and also identify scenarios which can be discussed with the population. Moreover, the promotion of traditional coastal management practices as well as hybrid forms of management combining tradition and modernity, could be implemented for sustainable use of marine resources. The recent development of very large MPA in French Polynesian and New Caledonian territories, is also part of this dynamic, even if we at present lack scientific evidence about the relation and the benefits between large and smaller MPA.

Another important development in the French Pacific territories is the potential relocation of activities according to projected climate change impacts. For example, frequent swells that hit the north of an atoll argue for investigating the feasibility of a relocation of the community activities (and residence?) to the south part of the atoll. Recent studies insist on the need to integrate populations, especially in low islands, into the formulation of this kind of public policy (Bambridge and et Latouche, 2016).

4. Conclusion

The diversity of the local circumstances across the vast Pacific Ocean expanse of French Pacific territories requires that all solutions to environmental problems need to account for local social-economic-ecological conditions, including local world views and values and local social organization. From this perspective, there is a need for widespread local monitoring to track trends in ecological, socio-economic and cultural sub-systems. The knowledge systems of the people of these territories are also diverse. They have also been formally recognized in public policy as these territories have developed a dialog between science and culture in order to increase the interactions between traditional and scientific knowledge systems (monitoring, fundamental research). Not only are participatory approaches and citizen science 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 at the heart of two converging movements: claims for local knowledge recognition and a progressive redefinition of landscape-planning methodologies. The Convention on Biological Diversity was a turning point for the reconsideration of the role of indigenous communities in creating and maintaining sustainable environmental systems. Local knowledge has been explored and some authors (Roué and Nakashima, 2002) have included other perspectives such as culture and history in ecological management. This new perspective adopts a more integrative and multidisciplinary approach. The dominant top-down planning models have proven inefficient in resolving environmental issues. By contrast, in French Polynesia, several projects have sought to allow indigenous people to participate to the discussion over sustainable marine ecosystems as with the (give full title as well as initials) "general plan for marine areas" (PGEM) of Moorea. Community-based research can be a tool for empowerment and capacity building. It can also help develop the transmission of ecological knowledge to future generations. Citizen science can contribute to local management as a tool for data collection. Recent experiments in French Pacific territories suggest rich possibilities can arise from greater collaboration between researchers and fishermen to identify changes in coral reefs and design polices and actions to ensure the future of coral communities.

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