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Iles Eparses (SW Indian Ocean) as reference ecosystems for environmental research



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ABSTRACT

TAAF ensures since 2007 the management of 5 small tropical islands lying in the southwestern Indian Ocean: the Iles Eparses. These islands share an exceptional natural heritage including many marine and terrestrial endemic species. At a regional scale the Iles Eparses are some of the most pristine ecosystems, largely preserved from anthropogenic impacts due to their geographical isolation and a historically very limited human occupation. In this context, TAAF wished that Iles Eparses become unique natural laboratories for earth scientists and environmental process observation – like climate change impacts – but also sustainable biodiversity sanctuaries for which the scientific community should provide baseline ecological data to inform on appropriate conservation tools. An inter-agency research consortium emerged in 2009 to meet this commitment for the Iles Eparses. This program was intended to set a science framework in accordance with France's objectives for Research and Conservation. It enabled between 2009 and 2014 the implementation of 18 cross-disciplinary research projects ranging from geology to ecology and represented by the variety of the proposed articles in this special issue. Altogether research projects have dramatically increased knowledge on the Iles Eparses' ecosystems and have provided the first overview of their diversity, their functions and their dynamics and its determinants. In particular applied research efforts have supplied a significant amount of ecological evidence that is now available to develop optimal conservation strategy to ensure the Iles Eparses' long-term biodiversity value. These findings point out that the continuation of research activity in the Iles Eparses should be considered a priority.

1. Iles Eparses overview

The Iles Eparses are a collection of French overseas island territories in the Western Indian Ocean managed by the French Southern and Antarctic Lands (French: Terres Australes et Antarctiques Françaises, TAAF, Box. 1) since February 2007 (fifth district of TAAF along with Kerguelen, Crozet, Saint Paul and Amsterdam, and the Terre Adélie). They are composed of the following islands: Europa, Juan de Nova and Glorieuses archipelago (Grande Glorieuse, Roches Vertes and Ile du Lys) in the Mozambique Channel (lying between 11°S and 22°S), and Tromelin north of La Réunion. The barely emerged coral reef Bassas da India is also included

within the Iles Eparses (Table 1 and Fig. 1).

All islands except Juan de Nova were classified as nature reserves in 1975. While the combined land area of the islands does not exceed 42 km², associated territorial marine waters represent a total of more than 640,000 km² (approximately 6% of the French maritime territory) (Table 1). The Iles Eparses are distributed along a climatic gradient ranging from sub-arid climate (Europa) to a more tropical wet climate (Glorieuses). Climate is characterized by the alternation of a warm and wet season (austral summer, from December to April) and a dry and cooler season (austral winter, from April to October). The Iles Eparses are all located in the regional pathways of depressions and tropical cyclones. In the Mozambique Channel, ocean currents are subjected to a very high spatial and temporal variability associated with the presence of many gyres (Schouten et al., 2003; Calzas, unpub. data). These oceanographic features significantly influence the dispersal ability

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Box 1

TAAF Administrative organization.

TAAF are placed under the authority of a senior administrator, who is designated since 2005 among the body of prefects. The prefect is both the government representative and the executive authority for the administration. TAAF present the particularity of having no permanent population and therefore have neither voters nor elected representatives or local deliberative assembly. The Prefect can nonetheless rely on a Consultative Committee and is assisted by a Secretary General, a Chief of Staff, several District Commanders and numerous project managers. The Prefect is empowered to manage all resources of the territory and more specifically to ensure the sustainable management of fisheries. In particular he is responsible for managing fish stocks within its territory and thus is in charge of editing fisheries guidelines, delivering fishing licenses, fixing the total allowable catches (TAC) as well as the dates for fisheries opening, and finally of setting and raising fishing fees. The prefect is, amongst other things, bound to guaranty the environmental conservation. TAAF regulations therefore mostly aim to provide a better framework for human activities based on up-to-date scientific knowledge and in compliance with national or regional regulations (e.g. IOTC, CITES).

to stay on the islands, respectively, in the context of their research projects and their land management missions.

2. Biodiversity sanctuaries

The Iles Eparses are among the last sanctuaries of marine and terrestrial tropical biodiversity in the South Western Indian Ocean. Geographic isolation and historically very limited human occupation have largely preserved these territories. Despite the introduction of some exotic species they are home to a remarkable native flora and fauna (including many endemic species) and well-preserved complex ecosystems such as mangroves and coral reefs. Each island supports high levels of species richness (Table 2) some being endemic to these ecosystems and others reaching very high densities. For example, Europa is a breeding ground for 8 seabird species including one endemic tropicbird species (*Phaethon lepturus europae*) and Juan de Nova is hosting one of the largest sooty tern colonies in the Indian Ocean (500 000 breeding pairs, Orłowski et al., unpub. data). Many reptiles and terrestrial birds, such as the Snake-eyed Skinks (*Cryptoblepharus bitaeniatus*) and the Malagasy White-eye (*Zosterops maderaspatanus* ssp. *voeltzkowii*), are also endemic to these islands (Probst, 1997; Sanchez and Probst, 2014). The Iles Eparses are major breeding sites for endangered marine turtles (*Chelonia mydas* and *Eretmochelys imbricata*). Europa is especially regarded as the most frequented site by breeding females in the Indian Ocean (8000–10000 each year, Bourjea et al., 2011). The Iles Eparses are also regionally important refuges for large

Table 1

Main geographic characteristics of the Iles Eparses (surface of geomorphologic units: Andrefouët et al., 2008).

	Tromelin	Glorieuses		Juan de Nova	Bassas da India	Europa	Total
		Glorieuses archipelago	Geyser Banks				
Geographical coordinates	15°53' S 54°31' E	11°35' S 47°18' E	22°21' S 40°21' E	17°03' S 42°43' E	21°28' S 39°42' E	22°21' S 40°21' E	
EEZ surface (km ²)	285 300	43 614		61 050	123 700	127 300	640 964
Surface of each geomorphologic unit (km ²)	6.9	201.36	256.79	212.17	96.33	49.13	822.68
Land-mass	0.85	4.79	—	5.48	0.1	31.63	42.85
Coral reef	5.42	26.92	47.8	43.47	49.18	10.50	183.29
Lagoon	0.63	169.65	208.99	163.22	47.05	7	596.54

(larval and adult) and recruitment and thus the connectivity of many marine species (Bourjea et al., 2007; Muths et al., 2011, 2012; Visram et al., 2010). Ocean eddies also have a strong influence on the distribution of primary production areas and therefore that of associated top predator species like tuna and seabirds (Weimerskirch et al., 2004).

The Iles Eparses were discovered by Europeans in the sixteenth century. Several attempts of human settlements on the islands took place in the past but all were unsuccessful mainly due to the lack of freshwater and harsh living conditions. These occupations were responsible for the introduction of exotic animal and plant species, some of which are now invasive such as black rats (*Rattus rattus*), cats (*Felis catus*), Mauritius hemp (*Furcraea foetida*) or Australian pines (*Casuarina equisetifolia*). The exploitation of guano and copra on Grande Glorieuse and Juan de Nova also generated the disappearance of some native terrestrial habitats. Today, the Iles Eparses do not house permanent human populations. However, Grande Glorieuse, Europa and Juan de Nova have been occupied year-round since 1973 by rotating military detachments (15 people including one gendarme) every 45 days in order to ensure French sovereignty. Similarly on Tromelin three TAAF agents take turns on the island every 2 months. Scientists and TAAF officers are regularly required

number of migratory species (shorebirds, raptors, etc.) often facing severe threats along their migratory roads. The Mozambique Channel and especially the Iles Eparses exclusive economic zones (EEZs) are also frequented by many species of marine mammals and fishes. In particular several species of sharks and rays, benefiting from protection measures under various international treaties and conventions (Bonn, Washington Convention CITES International Whaling Convention, Nairobi Convention) cross off the islands year-round. While the sampling effort of marine fauna and flora was not the same for the different taxonomic group and for each island, the present known marine biodiversity is very large. For example, the Iles Eparses harbor near 10% of fish species richness of the Western Indian Ocean area (Heemstra, unpub. data).

3. Anthropogenic pressures and threats

Although Iles Eparses natural ecosystems have been little altered over the past centuries, they are now facing numerous threats. These threats, resulting from climatic phenomena or from past and present human activities, are commonly encountered with varying intensities in tropical islands. In the Iles Eparses, the level of pressure exerted on the ecosystems highly varies from an island to

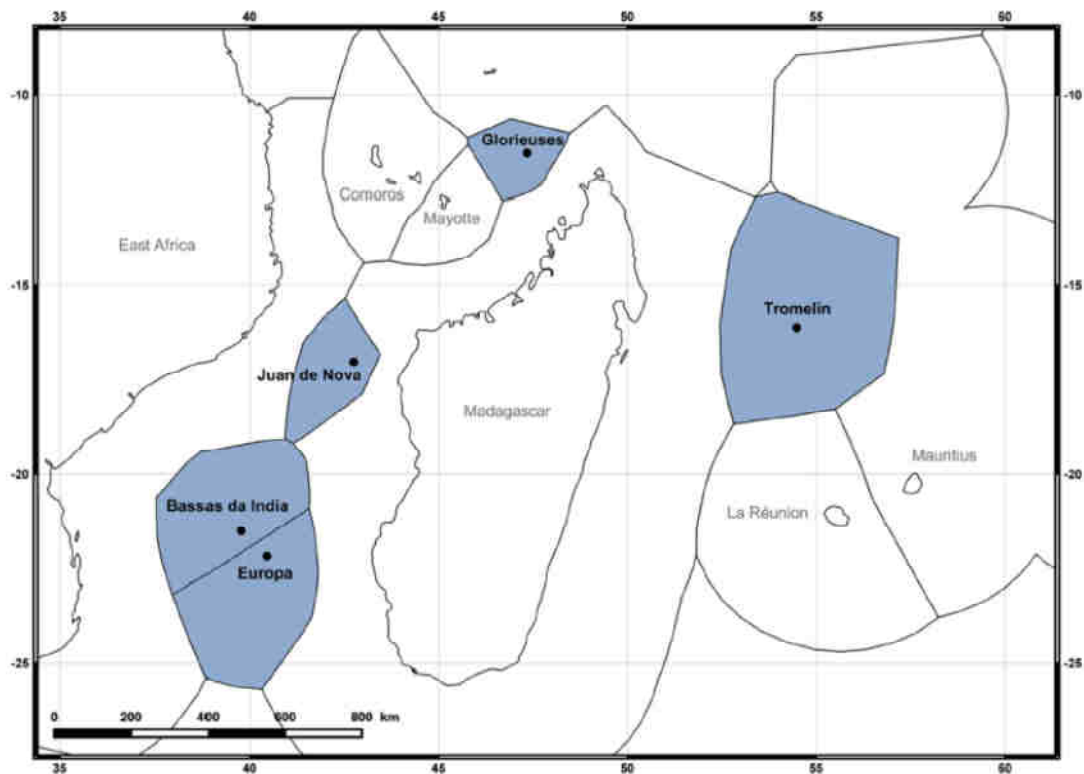


Fig. 1. Map of the Iles Eparses showing their location and the extent of their associated EEZs.

another depending on the history (past human occupation), geographical location and accessibility as well as on the richness of the marine resources (overview in Table 3).

Climate change, cyclones and pollution represent an approximately equal threat to all islands, Tromelin being slightly more exposed to cyclones. The effects of these threats on terrestrial and marine ecosystems will be monitored in each island in the coming years, with a special emphasis on the direct and indirect impacts of climate change (e.g. Chabanet et al., 2015). The results of this monitoring could be integrated to models in order to quantify, understand and predict the future effects of climate change on the islands. Models could also be extended to more complex ecosystems in the region, for example on similar sites exposed to a higher anthropogenic influence. TAAF have little resources to counter these global threats and so that their actions focus on conservation issues related to activities happening on or around the islands and building resilient ecosystems.

On all islands (except Bassas da India) the main threat to terrestrial ecosystems is the presence of alien invasive species. In fact, several animals and plants have been introduced throughout the recurring attempts to establish human settlements on the Iles Eparses over the past centuries. This heritage from past human activities has led to ecological disturbances of the original ecosystems (e.g. Russell and Le Corre, 2009). It has induced changes in biological interactions such as an increased predation pressure on native species (e.g. breeding seabirds, terrestrial endemic reptiles) as well as important modifications of the vegetation dynamics, resulting in the alteration of natural habitats and possibly leading to the extinction of native species (Le Corre et al., 2015; Ringler et al., 2015). The TAAF implement numerous programs and campaigns on each island to control or eradicate invasive species as well as to prevent new introductions (biosecurity plans). These

programs are built upon the last available knowledge on ecosystems functioning, resulting notably from research projects conducted in the Iles Eparses (e.g. Le Corre et al., 2015; Ringler et al., 2014, 2015). Programs currently running concern mostly, but not exclusively, (i) invasive species impacts assessment (feral goats on Europa and Australian pines on Grande Glorieuses), (ii) management strategy design (rats on all islands) and (iii) eradication operations implementation (Mauritius hemp on Europa and feral cats on Juan de Nova).

Historically limited to the islands themselves, human activities are now turned towards the marine environment and expand over the entire EEZ. The exceptionally rich marine resources are very attractive and their exploitation represents a new source of pressures and issues. An industrial fishery mainly targeting tropical tuna and spearfish is authorized in the outer part of the EEZ (Fig. 2). This fishery is strictly prohibited within the 12 nautical mile limit (territorial sea) of the Iles Eparses. Outside of the territorial waters, it is submitted to the deliverance of a license by TAAF. This high-sea fishery is mainly operated by French and Spanish seiners. Their activities are regulated by technical prescriptions. These guidelines aim at a sustainable use of the resources and a reduction of the impacts on the ecosystems. Despite a strict frame, the tuna fishery still generates high rates of by-catch (Bourjea et al., 2008; Poisson et al., 2014), especially when practiced over fish aggregating devices (FADs) (Amandé et al., 2008a, 2008b; Amandé et al., 2012; Chavance et al., 2011). Beside pelagic fishes, coral-reef associated species also are threatened. Coral reefs surrounding the islands or located within their EEZ (e.g. Geyser Bank within the Glorieuses EEZ) concentrate high densities of commercial fishes (Le Manach and Pauly, 2015; Wickel et al., 2009). A significant human population growth in the region (Pison, 2015) has generated a high demand for fish on the local markets of Mayotte, Madagascar and the

Table 2

Number of species identified on each island and for each taxonomic group (non-exhaustive dataset).

	Tromelin	Glorieuses		Juan de Nova	Bassas da India	Europa
		Glorieuses archipelago	Geyser Banks			
Terrestrial biodiversity						
Habitats	2	9	NR	12	NR	8
Flora ¹	17	121	NR	147	NR	90
Arthropods ²	31	180	NR	83	NR	103
Terrestrial reptiles ³	1	4	NR	3	NR	4
Terrestrial mammals (introduced) ⁴	2	2	NR	3	NR	2
Terrestrial avifauna (breeding) ⁴	0	9	NR	4	NR	5
	53	325	NR	252	NR	212
Marine biodiversity						
Plankton ⁵	18	179	—	—	—	18
Algae ⁶	—	215	—	36	—	134
Phanerogams	—	6	2	—	—	5
Sponges	—	—	—	15	—	24
Cnidarians ^{7–10}	26	110	37	256	15	125
Bryozoans	—	95	—	—	—	28
Brachiopods	—	—	—	—	—	—
Echinoderms ^{9–12}	1	54	30	23	—	39
Annelid worms	—	—	—	—	—	4
Molluscs ¹⁰	—	247	124	168	—	14
Arthropods ¹³	—	157	—	13	—	176
Tunicates	—	—	—	—	—	15
Bony fishes (osteichthyans) ^{10, 14–19}	95	349	388	299	301	380
Cartilaginous fishes (chondrichthyans) ^{20, 21}	—	14	14	17	10	16
Marine mammals ^{22–24}	2	5	5	5	2	7
Marine turtles ²⁵	1	2	NR	2	NR	2
Seabirds (breeding) ⁴	4	2	NR	2	NR	8
	147	1435	600	836	328	995
TOTAL	200	1760	600	1088	328	1207

—: no data available.

NR: not relevant.

¹ CBNM, 2013; ² Parnaudeau, 2008; ³ Probst, 1999; ⁴ Caceres, 2003; ⁵ Battistini et al., 1976; ⁶ Mattio and Zubia, 2012; ⁷ Gravier-Bonnet and Bourmaud, 2004; ⁸ Gravier-Bonnet and Bourmaud, 2006; ⁹ Quod and Garnier, 2004; ¹⁰ Quod et al., 2007; ¹¹ Conand et al., 2013a, 2013b; ¹² Mulochau et al., 2007; ¹³ Mulochau and Conand, 2009; ¹⁴ Poupin et al., 2012; ¹⁵ Chabanet et al., 2002; ¹⁶ Chabanet and Durville, 2005; ¹⁷ Durville et al., 2003; ¹⁸ Durville & Chabanet, 2010; ¹⁹ Fricke et al., 2013; ²⁰ Wickel et al., 2009; ²¹ Kiszka et al., 2009a; ²² Wickel et al., 2010; ²³ Kiszka et al., 2009b; ²⁴ Laran et al., 2012; ²⁵ Bourjea et al., 2011.

Comoros, resulting in high pressure on marine resources and decreasing catches. In response to the decrease of resource in the region, fishermen are now turning to the Iles Eparses, concentrating their efforts on the Geyser Bank and the other reefs around the Glorieuses archipelago, where fishing is strictly prohibited. Glorieuses and Juan de Nova are also submitted to the poaching of sea-cucumbers, organized from Madagascar to supply the Asian market (Conand et al., 2013b).

Despite these pressures on the marine environment, the unique natural heritage of the Iles Eparses remains very attractive for tourism and leisure activities. Those are mostly related to (i) the exploration of the marine natural heritage (snorkeling and SCUBA diving), (ii) sailing and (iii) recreational fishery. This latter is strictly forbidden but yet occurs in Bassas da India's EEZ supported by South African and Mozambican charter companies (Le Manach and Pauly, 2015). Although the number of requests to access the Iles Eparses (subject to authorization) has increased over the last years (Fig. 2), the majority of tourism and leisure activities actually happening on TAAF territory do not request prior authorization. Unauthorized and therefore uncontrolled activities generally come from neighboring islands (Mayotte, Madagascar) and from eastern Africa (Mozambique and South Africa) and may affect marine ecosystems.

Recent surveys have revealed that the Mozambique Channel may be rich in oil and gas resources (Brownfield et al., 2012). It could also represent a potential reservoir of polymetallic nodules, genetic resources or bioactive molecules. Waters under French jurisdiction around Europa, Bassas da India, Juan de Nova and the Glorieuses archipelago represent half of the area of the Mozambique Channel. Beside the risk for the terrestrial and marine

ecosystems associated to the exploitation of such resources, these findings could also refuel territorial claims over the Iles Eparses. This would threaten the sovereignty of France over the islands, which is nowadays the only warranty for the preservation of their exceptional natural heritage.

4. Conciliating biodiversity conservation and sustainable development

With an exceptional biodiversity and a preserved environment, the Iles Eparses represent a unique opportunity for the French government to fulfill its national and international commitments in terms of sustainable development and biodiversity conservation. TAAF also play a key role in the national strategy aiming at the constitution of a regional network of protected areas. Relying on their experience in the Iles Australes (since 1955), TAAF are currently elaborating a sustainable management model for the Iles Eparses based on a strong synergy between stakeholders and the scientific community. The acquisition of basic environmental knowledge represents a stepping stone for efficient management strategy. As such, TAAF promote long-term research projects to (i) understand ecosystems functioning (ii) establish evolution scenarios, (iii) identify impacts and threats resulting from human activities and (iv) build indicators of ecosystem health. Beside the acquisition of knowledge for management purposes, the TAAF intend to systematically supervise and control human activities in the Iles Eparses in order to reduce their potential impact on ecosystems. Technical prescriptions are regularly edited and updated to regulate tuna fishery, tourism and oil and gas resources prospection missions.

Table 3

Type and level of pressure identified for each island with the potential impact on natural ecosystems.

Pressure type	Potential impacts	Level of pressure				
		Tromelin	Glorieuses	Juan de Nova	Bassas da India	Europa
Large pelagic industrial fishery (tuna fishery)	Overfishing and/or overexploitation of pelagic resources	medium	medium	medium	medium	medium
Artisanal and semi-industrial reef fishery Illegal, unreported and unregulated (IUU) fisheries and poaching	By-catch and incidental catch					
	Overfishing and/or overexploitation of reef resources	none	high	none	none	none
	Overfishing and/or overexploitation of reef resources	none	medium	medium	none	none
Recreational activities and tourism	Holothurian fishery	none	high	high	none	none
	Marine turtles	none	low	none	none	none
	poaching					
	Fishing/spearfishing	none	high	low	high	low
Maritime traffic	Scubadiving/	none	high	low	high	low
	Snorkeling					
	Anchoring on coral reef	none	high	low	low	low
	Landbased tourism					
Mining activities	Disturbance of terrestrial wildlife	low	low	low	NR	low
	Vegetation trampling	low	low	medium	low	low
	Oil pollution	low	low	medium	low	low
	Acoustic pollution	NR	low	high	none	none
Macro-wastes	Oilspill/hydrocarbons pollution/deepsea ecosystems degradation	NR	none	none	none	none
	Loss of natural value of the island	medium	low	low	none	low
	Mortality of top predators including marine turtles (ingestion of plastic waste, entanglement, etc.)	medium	medium	medium	medium	medium
	Chemical pollution	low	low	low	NR	low
Landbased pollution	Loss of natural value of the island	low	low	low	NR	low
	Fires	medium	medium	medium	NR	medium
	Spread of invasive anthropophilic species	medium	low	low	NR	medium
	Loss of cultural heritage	NR	NR	NR	high	NR
Looting of underwater cultural heritage	Destruction of vegetation	high	medium	medium	NR	medium
	Beaches and sand dunes erosion	high	medium	medium	NR	medium
	Coral reef destruction	low	low	low	medium	low
	Coral bleaching	low	medium	medium	medium	low
Climate Change	Warming of marine waters					
	Intensification of tropical cyclones	high	medium	medium	NR	medium
	Beaches and sand dunes erosion	high	medium	medium	NR	medium
	Coral reef destruction	none	none	none	low	none
Exotic and/or invasive species	Ocean acidification	low	low	low	low	low
	Slowdown in coral and zooplankton growth	low	low	low	low	low
	Loss of nesting beaches surface (for turtles)	low	low	low	NR	low
	Modification of sex-ratio and survival rates in marine turtles hatchlings populations	medium	medium	medium	NR	medium
Native anthropophilic species	Increase in the predation pressure on native species	low	high	high	NR	high
	Changes in vegetation communities	low	high	high	NR	high
	Spread of anthropophilic species	medium	low	low	NR	medium

-: no data available.

NR: not relevant.

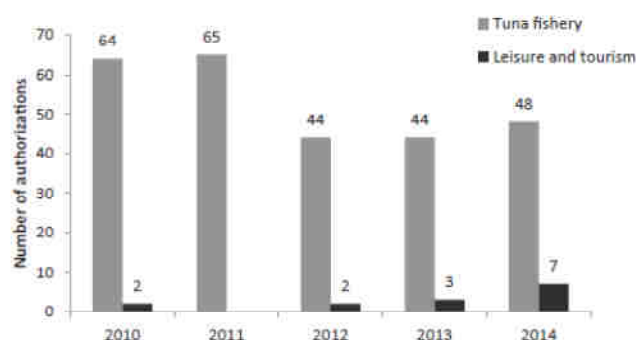


Fig. 2. Legal activities: evolution in the Iles Eparses between 2010 and 2014 (TAAF, unpub. data).

TAAF have built a strategy for the classification of the Iles Eparses as protected areas. Different conservation statuses exist, fixing a legal frame for the preservation of specific areas, habitats or species. TAAF must thus identify the most adapted conservation tools for each island, submits application files for their classification

and implement the resulting management plans. Europa and its territorial waters were recognized in 2011 as the 42nd Wetlands of international importance according to the RAMSAR Convention (www.ramsar.org). Europa is also registered within the "Network of Sites of Importance for Marine Turtles" of the Indian Ocean - South-East Asian Marine Turtle Memorandum of Understanding (IOSEA MoU) since 2014 (www.ioseaturtle.org) and will soon become a national nature reserve. A Natural marine park ("Parc naturel marin des Glorieuses") has been created in 2012, covering the entire EEZ of the Glorieuses Archipelago (www.taaf.fr and www.aieres-marines.fr). It provides TAAF with an official tool to preserve the marine environment around the islands and to simultaneously develop sustainable human activities (tuna and artisanal fishery, tourism). The management plan built for the next 15 years includes several actions related to the acquisition of knowledge, the conservation of ecosystems, education and training, sustainable development, exploitation and surveillance.

5. Reference ecosystems for global research

The international scientific community considers the geographical location and the conservation status of the Iles

Eparses provide a unique support for the development of cross-disciplinary research (Obura et al., 2012). Beyond the development of research in the tropics, the addition of the Iles Eparses as research sites promotes, within a single French public authority (TAAF), the setting up of large scale studies along a latitudinal gradient that extends from 11°S (Glorieuses) to 66°S (Terre Adélie). With an exceptional coverage of more than 80% of the Southern Hemisphere, TAAF offer a convenient and unique location for the establishment of an observatory on biodiversity and climate change impacts.

Following a conference organized at the French Senate in 2009, an inter-agency research consortium dedicated to the Iles Eparses was established in 2010. This consortium was driven and supported by the French National Center for Scientific Research (CNRS), the TAAF, the French Agency for Marine Protected Areas (AAMP) and the French Institute of Research for the Development (IRD), in partnership with the French Polar Institute "Paul Emile Victor" (IPEV), the French National Museum of Natural History (MNHN) and the French Research Institute for Exploitation of the Sea (IFREMER). Foundation of a consistent research framework was proposed for the Iles Eparses over the period 2010–2013 and beyond. With financial support of the consortium members, FAZSOI material support (transportation and accommodation) and the logistical support of the TAAF (coordination of scientific missions and provision of research vessel 'Marion Dufresne' in 2011), 18 research programs and nearly 120 field missions were carried out between 2011 and 2014.

This special issue of *Acta Oecologica* includes papers showing the diversity of these research projects. A large part of the research work concerned marine biological diversity exploration. Several projects were dedicated to the first description of the diversity of different communities: pelagic microorganisms (Bouvy et al., 2015), benthic cyanobacteria (Zubia et al., 2015), marine macrophytes (Mattioli et al., 2015). Others allowed to complete previous inventories of marine fauna (Crustacea: Poupin, 2015; Echinoderms: Conand et al., 2015) and/or to get new data to compare the diversity of coral and fishes communities of Iles Eparses to the ones of other areas of WIO (Chabanet et al., 2015). Not only species richness of the studied marine communities exhibited large values, but also biomass of upper trophic compartments such as fishes reach exceptional high values compared to other values reported in the WIO. Added to data from previous studies, the ones obtained on the Iles Eparses fish fauna allowed to assess both the level of their endemism in the WIO, which was higher than in any other region of the Indian Ocean, and to explore their evolutionary dynamics at the regional scale (Borsa et al., 2015).

The knowledge of the terrestrial vascular flora richness of the Iles Eparses was also improved through several fieldwork missions supported by the program (Bouillet, unpub. data): 236 taxa were now reported for the Iles Eparses. The composition of the flora of each island appeared to be greatly influenced by their geographical location that correspond to different climatic conditions and distances from the main pool of terrestrial flora (Madagascar, Seychelles). Only one strict endemic species was described in Juan de Nova. In the WIO, seabirds occur at high diversity and density (31 species, 7.4 million breeding pairs) and the Iles Eparses provide breeding and feeding grounds for a large part of their populations. The largest colony of sooty tern in the Indian Ocean occurs on Juan de Nova, Europa and Glorieuses with approx. 3 million breeding pairs. The study of foraging strategies of red-footed booby from Europa showed that these birds varied the duration and range of their foraging trips according to the breeding cycle and environmental variability (Mendez et al., 2015). Trips cover a general foraging area of 33 580 km². Thus, marine birds support a strong link between a large marine area around their nesting island, being

an efficient predator of fish and squid and a source of organic and inorganic nutrients for terrestrial and marine coastal primary producers. Among the other roles of seabirds related to their ability to form dense colonies and perform long trips, their ability to act as reservoirs and disseminators of parasites and pathogens was explored (McCoy et al., 2015). This study shed light on (i) the existence of relatively independent metacommunities of interacting species in the WIO, and (ii) the impact of seabird movements on parasite and pathogen circulation.

The Iles Eparses program also allowed testing the application of coupling remote sensing, geomorphological and biocenosis attributes to define the diversity of reef habitats of Europa and Juan de Nova (Andrefouët, unpub. data). Large differences have been observed in the diversity of habitats of the two studied islands that can help to both biodiversity pattern understanding and conservation goals. Regarding present climatic induced threats on Iles Eparses, the study of shoreline changes of Grande Glorieuse showed that despite the sea level has risen several centimeters in the last twenty years, the island has extended by 7.5 ha during the same period (Testut et al., 2015). This is the result of the predominance of shoreline aggradation due to sediment transfer from the sediment reservoir to the accumulation zone. As undisturbed or little disturbed systems, Iles Eparses may allow to study natural processes that can contribute to increase resistance of reef-island to sea level rise or climatic induced extreme events such as cyclonic or austral swells. The problematic of the recording and survey of these extreme events has been explored through terrestrial seismic stations that were able to efficiently detect and quantify swell, being thus a cheaper alternative to wave buoys for an automatic monitoring of oceanic events (Barrauol et al., 2015). The geomorphology and sedimentology studies of the Iles Eparses of the Mozambique Channel reveal that drowned terraces and emerged fossil reefs from the Glorieuses archipelago represent a potential unique record of past sea levels for the SW Indian Ocean (Jorjy et al., 2015). While the Iles Eparses are quite interesting ecological systems that offer a reference state to understand the consequences of anthropogenic impacts on island ecosystems, they also appear as excellent sites to observe both climatic changes and their effects.

Some of the above-mentioned scientific outcomes will also provide stakeholders with guidelines for the implementation of relevant management measures for the Iles Eparses in order to maintain the integrity of ecosystems and face the multiple pressures they undergo. All results relevant to management are now included in conservation plans supported by the TAAF (e.g. Glorieuses Marine Natural Park Management Plan, Marine Turtle National Action Plan, Europa RAMSAR Management Plan and National Natural Reserve application file). Beyond the specific results of the "Iles Eparses" program presented in the papers of this special issue of *Acta Oecologica*, we wish to outline the fact that this program by its multidisciplinary opening allowed to reinforce the links among the scientific of different disciplines and contributed to build a knowledge background on the Iles Eparses that will be useful for next fundamental and applied projects.

6. What future for the Iles Eparses?

TAAF strategy for sustainable development of the Iles Eparses, which is still being built, must integrate all stakes at play: a complex regional context, an increasing pressure on the resources and the ambitions of the French government for these islands. The future of the Iles Eparses is thus following a clear pathway whose main objective is to prevent biodiversity erosion with the development of conservation tools adapted to the specific context of each island and the development of sustainable activities. It

includes a better control of industrial high-sea tuna fishery, artisanal fishery and tourism. Given the relatively low number of stakeholders accessing the area and the legislative specificity of TAAF, the management of the Iles Eparses represents a unique opportunity to test and implement new models of sustainable use of the resources. Sharing this local experience through cooperation projects could benefit other countries in the Indian Ocean region and would especially make sense when applied to highly migratory species like tuna.

Research activities are essential to acquire the necessary knowledge and allow for the design of Iles Eparses management strategy. The research consortium dedicated to the Iles Eparses came to its end in December 2013 but the continuity of scientific research on the territory has been ensured by the construction of a new consortium and by (i) providing logistic support, (ii) facilitating the access to the islands and (iii) improving the working conditions for the scientists. In this purpose, laboratories are being renovated and equipped on each island. TAAF is also reinforcing national and international collaboration between scientists and managers through cooperation projects. Such a project, funded by the Xth regional European Development Fund, is currently taking place, aiming to the « sustainable management of the natural heritage in Mayotte and the Iles Eparses ». In addition, the deployment of a larger panel of automatic recording stations and the organization of recurring monitoring surveys in the Iles Eparses could serve as a basis for the development of an observatory for climate change and biodiversity in the Indian Ocean. Data would improve our understanding of the processes at stake in the region and could bring new insights for international organizations such as the Intergovernmental Panel on Climate Change (IPCC) or the Intergovernmental Platform on Biodiversity & Ecosystem Services (IPBES).

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