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A terrestrial and marine nature reserve in the NW Mediterranean, Scàndula (Corsica): Biodiversity and lessons from 46 years of management

Charles-François BOUDOURESQUE[1*], Jean-Marie DOMINICI[2], Olivier DURIEZ[3], Patrick ASTRUCH[4], Laurence LE DIRÉACH[4], Frédéric MÉDAIL[5], Enric SALA[6], Thomas SCHOHN[4], Nardo VICENTE[7]

[1]Aix-Marseille University and University of Toulon, MIO (Mediterranean Institute of Oceanography), CNRS, IRD, Campus de Luminy, Marseille, France.
[2]Parc naturel Régional de Corse (Parcu di Corsica), Corti and Ajacciu, Base de gestion 20245 Galeria, Corsica, France.
[3]Centre d'Écologie Fonctionnelle et Évolutive, Université de Montpellier, 1919 Route de Mende, 34293 Montpellier CEDEX 5, France.
[4]GIS Posidonie, Aix-Marseille University, OSU Pythéas, Campus de Luminy, Marseille, France.
[5]Institut méditerranéen de biodiversité et d'écologie marine et continentale (IMBE), Aix Marseille University, Avignon Université, CNRS, IRD. Campus Aix, Technopôle de l'Environnement Arbois-Méditerranée. 13545 Aix-en-Provence CEDEX 4, France.
[6]National Geographic Society, Washington, DC, USA.
[7]Institut méditerranéen de biodiversité et d'écologie marine et continentale (IMBE), Aix Marseille University, Avignon Université, CNRS, IRD, and Institut Océanographique Paul Ricard, île des Embiez, Six-Fours-les-Plages, France.
**Corresponding author: charles.boudouresque@mio.osupytheas.fr*

Abstract. The Scàndula Nature Reserve (SNR), both terrestrial (919 ha) and marine (664 ha), was established in 1975. The marine part of the SNR includes a No-Take Zone (82 ha) where any form of fishing is prohibited, and a partial reserve, where artisanal fishing is authorized, under a number of constraints, while recreational fishing is banned. The SNR has been frequented by man since the Neolithic period, but never accomodated permanent human dwellings; it is now uninhabitated. Terrestrial ecosystems include forests and high *maquis*, low *maquis*, *Cistus* shrublands, low shrublands, more or less nitrophilic lawns, coastal rocks with halophilic vegetation, vegetation of inland rocks and cliffs, and other very localized plant communities. Fifty species of birds (46 % of the whole of the Corsican avifauna, including the iconic osprey *Pandion haliaetus*), 8 species of bats, 12 species of amphibians (including *Discoglossus sardus*), 33 species of ants, 64 species of parasitic Hymenoptera, 56 species of Lepidoptera, 138 species of spiders, 710 species of vascular plants (a third of the floristic richness of Corsica) and 57 species of bryophytes occur in the SNR. Non-flying mammalians are all introduced species, while all native species were extirpated by humans shortly after they colonized Corsica, ~10 000 years ago. The small islands and islets are characterized by high degree of originality in the structure and functioning of the terrestrial communities and in their biodiversity.

Forest vegetation during the climatic optimum of the Holocene (between ca. 7 500 and 4 800 years BP) was dominated by the tree heather *Erica arborea* and the strawberry tree *Arbutus unedo*. The holm oak *Quercus ilex* was, then, confined to rupicolous situations and its occurrence was negligible; it is only with the clearings and the development

of pastoralism that the holm oak has been able to spread. The territory of the SNR, apparently very natural and without human impact, is actually the legacy of uninterrupted agro-sylvo-pastoral pressures over millennia. But with almost no human impact for more than 50 years, the absence of wildfires and also much less pressure from grazing by cows and goats, the natural dynamics is accelerating. The vegetation of the SNR shows a rapid progression of the vegetation cover between 1983 and 2007. The main feature is the doubling of the surface area of the high *maquis*.

Marine ecosystems harbour 454 species of macroalgae (90 % of the Corsican flora), 32 species of echinoderms, 265 species of molluscs (including *Patella ferruginea* and *Pinna nobilis*), 8 species of sea slugs and 142 species of fish (including the dusky grouper *Epinephelus marginatus* and the meagre *Sciaena umbra*). In addition, the high number of parasites testifies to the good health of the ecosystems. Canopy-forming *Cystoseira* forests are well represented, while they have been extirpated by overgrazing, a consequence of overfishing, in most of the Mediterranean. The ecosystem diversity includes *Lithophyllum byssoides* algal rims, *Cystoseira* forests, *Posidonia oceanica* seagrass meadows and coralligenous outcrops. The vulnerable giant limpet *Patella ferruginea* is present. The fan mussel *Pinna nobilis* was particularly abundant in the SNR, before it was recently extirpated by a disease, as in most of the Mediterranean Sea. Populations of the precious red coral *Corallium rubrum,* over-exploited for centuries in the Mediterranean, showed at SNR an unexpectedly high biomass (before recent heatwaves), perhaps corresponding to the baseline. The Mediterranean monk seal *Monachus monachus* was methodically exterminated by fishermen in the early 1970s, just before the establishment of the SNR. The reasons for this slaughter deserve to be objectively examined: was it a true competitor of the fishermen, or just a scapegoat?

Overall, the SNR has been an undeniable success. It owes this to nearly 50 years of uncompromising protection and efficient management, to the unsparing dedication of wardens and curators, to a symbiosis between management, agents and independent scientists and to a Scientific Council that was not just window-dressing. Among the most remarkable successes is the reconstitution of the osprey *Pandion haliaetus* population, which was almost extinct in the early 1970s, and the coexistence of a profitable artisanal fishing industry with marine biodiversity sometimes close to the baseline. But these successes should not mask failures. The decree creating the reserve has not been updated; overcrowding by boats, in particular sightseeing boats, was neither anticipated nor limited, and is now out of control; the degradation of the *Posidonia oceanica* meadows and the recent failure of ospreys to produce fledgings are other examples. The reserve is too small to be fully efficient and has not been enlarged; the Council of Europe, on the basis of the failure to respond to its long-standing requests, withdrew the European Diploma from the reserve in 2021.

The terriritory of the SNR is today among the best known in the Mediterranean. In addition, the SNR has constituted a sort of scientific hotbed: many major discoveries, now widely known and used, of great importance for management, originated in Scàndula. Unfortunately, the success of the SNR, which has been iconic in the Mediterranean, could be jeopardised in the near future by uncontrolled frequentation which could destroy the very features which constitute the justification of the reserve and at the same time its attraction for tourists.

Keywords: Artisanal fishery, Corsica, Frequentation, Giant limpet *Patella ferruginea*, *Lithophyllum byssoides* rim, Management, Monk seal *Monachus monachus*, Nature reserve, Osprey *Pandion haliaetus*, Reserve effect, Terrestrial realm.

***Résumé*. Une réserve naturelle terrestre et marine dans le NW de la Méditerranée, Scàndula (Corse) : Biodiversité et enseignements de 46 ans de gestion.** La Réserve naturelle de Scàndula (RNS) est à la fois terrestre (919 ha) et marine (664 ha). Elle a été créée en 1975. Elle comporte une réserve intégrale (*No-Take Zone*) de 82 ha, où toute forme de pêche est prohibée, et une réserve partielle où la pêche artisanale est réservée aux pêcheurs autorisés (sous réserve d'un certain nombre de contraintes) mais où la pêche de loisir est interdite. Le site a été fréquenté par l'homme depuis le Néolithique, mais n'a jamais abrité d'habitats permanents ; il est maintenant inhabité. Les écosystèmes terrestres comportent des forêts et des maquis élevés, des maquis bas, des cistaies, des fruticées basses, des pelouses plus ou moins nitrophiles, des peuplements de rochers maritimes halophiles, des peuplements de rochers et falaises non maritimes, ainsi que d'autres communautés très localisées. Cinquante espèces d'oiseaux (46 % de l'avifaune de Corse), dont l'emblématique balbuzard *Pandion haliaetus*, 8 espèces de chauves-souris, 12 espèces d'amphibiens (dont *Discoglossus sardus*), 33 espèces de fourmis, 64 espèces d'hyménoptères parasites, 56 espèces de lépidoptères, 138 espèces d'araignées, 710 espèces de plantes vasculaires (un tiers de la richesse floristique de la Corse) et 57 espèces de bryophytes ont été recensées à Scàndula. Les mammifères non-volants sont tous des espèces introduites, qui ont remplacé la faune indigène, exterminée par l'homme après qu'il ait peuplé la Corse, il y a environ 10 000 ans. Les petites îles et îlots présentent une forte originalité dans la structure et le fonctionnement des communautés terrestres et dans leur biodiversité.

Durant l'optimum climatique de l'Holocène (environ 7 500 à 4 800 ans BP), la forêt était dominée par la bruyère arborescente *Erica arborea* et l'arbousier *Arbutus unedo*. Le chêne vert *Quercus ilex* était alors confiné à des situations rupicoles et son rôle était négligeable ; ce n'est qu'après les défrichements et le développement du pastoralisme qu'il a étendu son emprise. Le site de la RNS, en apparence très naturel et sans impact humain, est en fait l'héritage d'une pression agro-sylvo-pastorale ininterrompue depuis des millénaires. Toutefois, en l'absence presque complète d'impact humain depuis plus de 50 ans, en l'absence d'incendies et avec une pression réduite de paturage par les vaches et les chèvres, la dynamique naturelle du peuplement s'accélère. La végétation est en évolution rapide et, entre 1983 et 2007, par exemple, la surface du maquis élevé a doublé.

Les écosystèmes marins hébergent 454 espèces de macroalgues (90 % de la flore de Corse), 32 espèces d'échinodermes, 265 espèces de mollusques (dont *Patella ferruginea* et *Pinna nobilis*), 8 espèces de limaces de mer et 142 espèces de poissons (dont le mérou *Epinephelus marginatus* et le corb *Sciaena umbra*). Par ailleurs, le nombre élevé de parasites témoigne de la bonne santé des écosystèmes. Les forêts de grandes algues brunes du genre *Cystoseira* sont bien représentées ; contrairement à une grande partie de la Méditerranée, elles n'ont pas été éliminées par le surpâturage, conséquence de la surpêche. La diversité des écosystèmes comporte également les trottoirs à *Lithophyllum byssoides*, les herbiers à *Posidonia oceanica* et les concrétionnements coralligènes. La patelle géante *Patella ferruginea*, espèce en régression dans une grande partie de la Méditerranée, est présente. La grande nacre *Pinna nobilis* a été particulièrement abondante dans la RNS, avant d'être récemment décimée par une maladie. Le corail rouge *Corallium rubrum*, surexploité depuis des siècles en Méditerranée, a présenté à Scàndula (avant une récente vague de chaleur) des biomasses et densités incroyables, peut-être représentatives de la *baseline*. Le phoque moine *Monachus monachus* a été méthodiquement exterminé par les pêcheurs, au début des années 1970s, juste avant la création de la RNS ; il serait intéressant de réexaminer objectivement les raisons de ce massacre : était-il vraiment un compétiteur des pêcheurs, ou bien simplement un bouc émissaire commode ?

Globalement, la réserve naturelle de Scàndula a été un indéniable succès. Elle le doit à près de 50 ans d'une protection sans concession et d'une gestion efficace, à des agents et conservateurs passionnés, à une symbiose entre direction, agents et scientifiques indépendants et à un Conseil scientifique qui n'était pas une vitrine. Parmi les succès les plus remarquables figure la reconstitution de la population de balbuzard *Pandion haliaetus*, presque éteinte au début des années 1970s et la coexistence d'une pêche artisanale rentable avec une biodiversité marine peut-être proche de la *baseline*. Mais ces succès cotoyent des échecs. Le décret de création de la réserve, aujourd'hui inadapté, n'a jamais été mis à jour ; la surfréquentation par les bateaux, en particulier les bateaux de promenade, n'a pas été anticipée, ni limitée, et est devenue hors de contrôle ; la dégradation des herbiers à *Posidonia oceanica* et l'échec de la reproduction des balbuzards en sont des exemples ; la réserve, trop petite pour être efficace, n'a pas été agrandie. Le Conseil de l'Europe, sur la base de la non-réponse à ses demandes de longue date, a retiré à la RNS son diplôme, en 2021.

Le site de Scàndula est aujourd'hui l'une des régions les mieux connues de Méditerranée. De plus, la RNS a constitué une sorte de *start-up* scientifique : de nombreuses découvertes majeures, avec des implications fortes pour la gestion, sont nées à Scàndula. Malheureusement, le succès de la RNS, emblématique en Méditerranée, pourrait être remis en question dans un proche avenir par une fréquentation incontrôlée qui risque de tuer ce qui constitue la justification de la réserve et son attractivité pour les touristes.

Mots-clés : Balbuzard *Pandion haliaetus*, Corse, Domaine terrestre, Effet réserve, Fréquentation, Gestion, Patelle géante *Patella ferruginea*, Pêche artisanale, Phoque moine *Monachus monachus*, Réserve naturelle, Trottoir à *Lithophyllum byssoides*.

1. Introduction

The Scàndula Peninsula is located on the west coast of Corsica (France, Mediterranean), between the fishing village of Galeria, to the north, and the recent tourist resort of U Portu, to the south (Fig. 1). Although it was inhabited in the past, and has two so-called 'Genoese towers' (L'Elbu Cove and Gargalu Island) intended to protect Corsica against centuries of terrifying raids by Arab (Barbary) pirates, the Scàndula peninsula is today uninhabited (Antona *et al.,* 1981a).

Scàndula's geological history is unique. It is an ancient volcano, dating from the Permian (about 250 million years – Ma – ago), formed in particular of red lava (rhyolites). At the time when this volcano was active, Corsica and Sardinia were not islands, but were part of the European continent. Much later, between 30 and 14 Ma ago, Corsica and Sardinia broke away from the continent and moved towards their current position, under the influence of the nothwards push of the African continent (in fact, the African geological plate). Scàndula represents one half of the old volcano, while the Estérel massif, in Provence (mainland France), constitutes the other half, which has remained in place (Antona *et al.,* 1981a; Gauthier, 1992, 2002; Bronner, 2004; Gauthier, 2007).

The Scàndula peninsula constitutes a breathtaking landscape (Figs. 2, 3). For the millions of tourists who visit Corsica, Scàndula is an iconic site (Richez, 1988; Molinier, 1992; Richez and Richez Battesti, 1989, 2007). There is something magical about its red cliffs, battered by the waves, for sailors arriving from the sea. There is also the smell of the *maquis*. French Emperor Napoleon Bonaparte (1769-1821) said: 'with the perfume of its *maquis*, from afar, eyes closed, I would recognize Corsica' (*Au parfum de son maquis, de loin, les yeux fermés, je reconnaîtrais la Corse*).

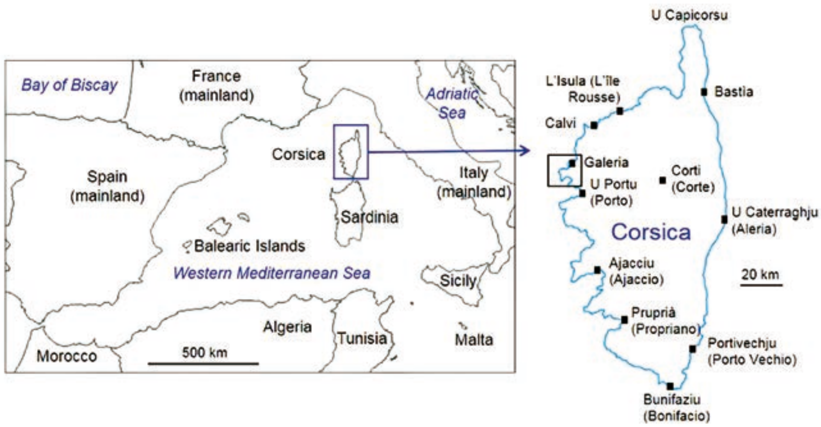

Figure 1. Map of the western Mediterranean Sea (left) and of Corsica (right). The box shows the location of the Scàndula Nature Reserve (SNR).

Figure 2. The Scàndula Peninsula. Photo © Charles-François Boudouresque.

Corsican toponymy is of Tuscan (Italian) origin, from the time when Corsica was under the rule of the Republic of Genoa; this toponymy was taken over by France when Genoa ceded Corsica to France, in the 18th century. Here, we have chosen to adopt the modern Corsican toponymy, which differs to a greater or lesser extent from the Tuscan (Fig. 1) (Aedis, 2016; Canioni, 2017).

Figure 3. Palazzinu Islet and Punta Palazzu seen from Gargalu Island (Scàndula). Photo © Frédéric Médail.

2. The establishment of the Scàndula Nature Reserve, in 1975

The establishment of the Scàndula nature reserve (SNR) was the culmination of a fifteen-year process (Richez and Richez-Battesti, 1970; Dominici, 2007a). **(i)** In 1963, the Association for the Protection of Nature in Corsica (APNACO) was set up. **(ii)** In 1968, the Corsican Assembly (*Conseil Général de Corse*) decided to call on a number of prestigious scientists for an assessment mission, which was called the 'Mission Bourlière': François Bourlière, Jean Dorst, Luc Hoffman, Roger Molinier, Pierre Pfeffer and Michel Terrasse. They strongly recommended the creation of a Regional Natural Park (Richez and Richez-Battesti, 1970). **(iii)** Roger Molinier (1927-1991), member of the 'Mission Bourlière' and of the Economic and Social Council of Corsica, was one of the main driving forces, with François Giacobbi (1919-1997), a leading Corsican elected official, behind the foundation of the Regional Natural Park of Corsica (RNPC - *Parcu di Corsica*) in 1970 (Richez and Richez-Battesti, 1970; Boudouresque, 1992; Boudouresque and Olivier, 2013; Luciani, 2016). **(iv)** Mazodier and Balland (1970) made 5 dives in the future Scàndula reserve; their conclusions were very cautious as to its state (poverty, wealth, human impacts). **(v)** In an unpublished document from 1973, Roger Molinier underlined the interest of protecting the Scàndula area, both in terms of the natural habitats present and the human pressures which were beginning to increase, such as boating, anchoring, spear fishing and poaching (Le Brun, 1972). **(vi)** In February 1975, Marc Verlaque and one of the authors of this article (CFB) carried out a field mission to Scàndula; they provided a first description of its habitats (*Lithophyllum byssoides* algal rims, *Cystoseira* forests, *Posidonia oceanica* meadows, and coralligenous) and of the remarkable diversity of species to be found there (Verlaque, 1975). **(vii)** In May 1975, the CNEXO (National Centre for the Exploration of the Oceans) and the FFESSM (French Federation for Underwater Studies and Sports) organized the COMETES expedition, aboard the yacht Rara-Avis, in the region of Scàndula, in order to establish a baseline of the marine species, populations and ecosystems (Figs. 4, 5) (Anonymous, 1975; Boudouresque, 1980).

It is interesting to note that, according to former fishers (*in* Felici, 1982), the choice of Scàndula as the site of the reserve, rather than the gulfs of Galeria or Ghjirulatu, was due to the fact that the sector, difficult of access, and with often rough seas, was of little, or less, interest than Galeria and Ghjirulatu for artisanal fishermen.

The Scàndula nature reserve (SNR) was established by the French decree of December 9th, 1975 (Decree number 75 1128). It is located in the municipality of Osani. It belongs to the RNPC whose coastline, 80 km long (on a scale of 1/25 000), extends from Galeria (in the north) to Capu Rossu (in the south), including the Gulf of Portu. The charter of the RNPC, approved in 1971 by the French Ministry of the Environment, provided for the creation of nature reserves (Leenhardt, 1992; Franceschi, 2007; Biber, 2019). The objectives of the SNR were **(i)** to ensure the protection of representative natural environments, which may thus serve as conservation areas, and **(ii)** to enable the study of these environments, their functioning and patterns of change, as a field laboratory; **(iii)** in addition, the protection of living organisms encourages the repopulation of neighbouring areas and enables the reserve to also play a significant role as a ‘reservoir’ of potential resources (Biber (2019).

Figure 4. Onboard the yacht Rara-Avis: some participants in the COMETES expedition to the western coast of Corsica, May 1975. Top (from right): X, X, Jean Vacelet, Charles-François Boudouresque, X, Jean-Georges Harmelin. Bottom (from right): X, Gilbert Barnabé, X, Michel and Patrick Cantou, Nardo Vicente. Gérard Altman, Gabriel Béranger. Patrice Lardeau and André Védrine also took part in this expedition. Photo © Michel Cantou (courtesy of the author).

The SNR was the France's first dual terrestrial and marine reserve. The land part (919 ha) belongs, roughly one third each, to the municipality of Osani, to a state agency (*Conservatoire des espaces littoraux et lacustres*) (since 1992) and to private owners (Richez, 1988; Leenhardt, 1992; Franceschi, 2007; Biber, 2019). The marine part of the reserve includes an integral reserve (82 ha), where any form of fishing (recreational and artisanal) is prohibited, and a partial reserve (582 ha)[1], where recreational fishing is banned while artisanal fishing is authorized, under conditions which will be detailed in the chapter devoted to management (Meinesz *et al.,* 1983; Meinesz and Blanfuné, 2015; Meinesz, 2020a).

Two separate sets of regulations were drawn up to meet the objectives of the SNR. **(i)** Prohibition of a set of activities in the land area (hunting, introduction of animal and plants, disturbing of animals by shouting or making noise or by photography, picking of plants, bivouacking and camping, lighting of fires, refuse disposal, collecting of minerals and fossils, motor vehicle traffic), with the exception of

[1] The erroneous data which appears in many documents (1 000 ha in total for the marine reserve) has been corrected (after Meinesz, 2020a).

agricultural activities and grazing that may continue. **(ii)** Prohibition of a set of activities in the marine area (mooring of boats for more than 24 h, angling, spear fishing, throwing waste into the sea, scuba diving), in particular prohibition of fishing in the integral reserve and prohibition of fishing except for artisanal fishermen with boats not exceeding 10 gross registered tons and 50 horsepower engine in the partial reserve; navigation was unrestricted, while speed limits might be imposed by the maritime authority (*préfet*); it is currently 9 km/h (5 knots) (Biber, 2019). The ban on recreational fishing was the trade-off which induced fishermen to accept the imposition of the integral reserve.

Figure 5. The yacht Rara-Avis at Scàndula, May 1975. In the foreground, an inflatable boat from the Regional Natural Park of Corsica (RNPC). Although the Nature Reserve had not yet been officially established, the RNPC already had marine wardens and boats. Photo © Jean-Georges Harmelin (courtesy of the author).

3. Main scientific topics

3.1. Ancient human presence

Man was present at Scàndula in the Neolithic period: an arrowhead made from local rock (rhyolite) was discovered on the island of Gargalu (which at the time was not yet an island), dating from the 6th to the 5th millennium BCE (Vigne *et al.,* 1993; Weiss, 2003, 2007a; Allegrini-Simonetti *et al.,* 2008). Roman settlements are attested, in particular at L'Elbu (Alfonsi and Gianetti, 1983).

However, after the Roman period, the site does not seem to have accomodated villages or even permanent human dwellings: at most fifteen shepherds' huts ('*stazzu*' in Corsican) (Fig. 6) (Richez and Richez-Battesti, 1992). These stone huts had a juniper wood roof, were covered with red earth (*'tarra rossa*'), and had adjoining shelters for goats ('*chjostru*') (Weiss, 2007b). Even the village of Ghjirulatu (located outside the SNR) did not exist at the end of the 18th century (Richez and Richez-Battesti, 1989). The area was, however frequented by shepherds from Èvisa, Ota and especially from the region called Niolu, with their flocks of sheep and goats; they arrived from October and left in May. Between the beginning and the middle of the 20th century, this transhumance disappeared (Antona *et al.,* 1981a; Ruggieri, 1981; Alfonsi and Gianetti, 1983; Weiss, 2007b). Hunting targeted the wild boar, and from the 20th century abandoned goats that had become feral. In the 19th century and early 20th century, a few crops existed in Scàndula, as evidenced by a dozen threshing floors ('*aghja*' in Corsican) (Fig. 6); it was mainly wheat, to a lesser extent barley. A small vineyard existed in the valley of L'Elbu; it was still visible in 1981 and its wine enjoyed a certain reputation (Fig. 7). The high point of cultivation was probably between 1820 and 1870; the soils are stony, very infertile, and maintained by a few hand-made dry stone walls ('*murate*' in Corsican). The population was very poor and cultivation has now been totally abandoned (Antona *et al.,* 1981a; Alfonsi and Gianetti, 1983; Ruggieri, 1981; Gianetti, 1986; Richez and Richez-Battesti, 1992). The exploitation of the *maquis* (*Arbutus unedo, Erica arborea, Phillyrea* spp., *Quercus ilex*) to produce charcoal, common throughout the south of Corsica, in particular in the region of Galeria-Ghjirulatu, since the middle of the 19th century, only concerned Scàndula between 1929 and 1931; up to 150 workers from Tuscany (Italy) and 7 mule drivers from Orezza (eastern Corsica) were employed; the charcoal was exported to Spanish Catalonia (Antona *et al.,* 1981a).

Figure 6. **Left**. A shepherd's stone hut ('*stazzu*') at L'Elbu. Note the pillars and the roof made of juniper wood (*Juniperus oxycedrus*). **Right**. A threshing floor ('*aghja*') at L'Elbu. Photos © Jean-Marie Dominici.

Figure 7. **Left**. A cellar under shelter ('*u palmentu*') for the fermentation of grape juice into wine at L'Elbu. Note the roof covered with earth. **Right**. A bread oven ('*u fornu*'), in the wall of a stone hut. Photos © Jean-Marie Dominici.

The western Mediterranean, from Sicily (Italy) to Corsica and even sometimes to the coast of Provence (France), was ravaged, from the 9th to the beginning of the 19th century, by Barbary pirates (Turkish and Arab). These pirates, whom the Corsicans called '*i turchi*', coming from the sea, carried out rapid raids, sometimes far inland; they killed, burned, and stole only what could be taken away. Men in their prime and women were carried off to slave markets and harems, respectively. The result was a widespread abandonment of the shores, the villages taking refuge far from the sea, in impregnable eyries. Scàndula had even become a permanent haunt for Barbary pirates, from which they attacked passing ships and launched raids against the inhabitants of the interior (Alfonsi and Gianetti, 1983; De Moro, 1986; Rota-Guerrieri, 2003, 2007). In an attempt to protect Corsica, then under the dominion of the Republic of Genoa, between the 16th and the end of the 17th century, 80 towers were built along the shore, which tradition designates under the name of 'Genoese towers' (Alfonsi and Gianetti, 1983; Richez and Richez-Battesti, 1992; Altamura, 2016; Graziani, 2019). There are two in the SNR: L'Elbu and Gargalu (Fig. 8). Two other towers are close by: Galeria to the north (built in 1541?) and Ghjirulatu to the south (built in 1552-1570) (Antona *et al.,* 1981a; Rota-Guerrieri, 2003, 2007). Until 1830, a garrison occupied the Genoese tower at Ghjirulatu (Richez and Richez-Battesti, 1992). It was only after 1830, when Algiers was taken by the French, that the villages began their descent towards the sea, throughout the Mediterranean (De Quatrefages, 1854); in Corsica, the maritime part of the village resulting from this relatively recent descent towards the sea is called *marina*. U Portu (south of Scàndula) is thus the *marina* of Ota, the invulnerable eagle's nest located up in the mountains, at ten kilometres away. Of course, a marina, in the modern English sense, can be present in a *marina*, which is the case at U Portu.

The anchorages of Galeria, L'Elbu, Gargalu and Ghjirulatu have been frequented from Antiquity (from at least the 5th century BCE) to modern times; they served as a dumping ground for deliberately discarded objects (amphorae and broken dishes). The possible remains (amphorae) of several shipwrecks have been observed at the foot of Porri islet. Since the deep sea is close to the coast, any wrecks are undoubtedly too deep to be studied by scuba diving (Allegrini-Simonetti, 2003, 2007; Allegrini-Simonetti *et al.,* 2008).

Figure 8. The Genoese tower on Gargalu Island, in the core of the Scàndula Nature Reserve. Its construction in about 4 months in 1610, on a steep island, without water, without food resources, without wood, without limestone for lime, was a technical feat. In the near background, Gattaghja Bay and Punta Muchilina. In the far background, the southern shore of the Gulf of Portu, with the Calanche di Piana. Photo © Frédéric Médail.

3.2. The terrestrial ecosystems

Following the establishment of the Scàndula Nature Reserve (SNR), the study of terrestrial ecosystems and the biodiversity of several taxonomic groups has seen significant development. The terrestrial vegetation of the Scàndula peninsula is now rather well known as a whole, thanks to the work on the characterization of the typology and dynamics carried out by Jacques Gamisans (Gamisans and Muracciole, 1984; Gamisans, 1988, 1992, 1995), then by Frédéric Bioret (Bioret, 2002; Bioret *et al.,* 2008, 2009). A total of 43 vegetation units were inventoried and grouped into eight major groups (Bioret et al., 2008, 2009): forests and high *maquis*, low *maquis*, *Cistus* shrublands, low shrublands, more or less nitrophilic lawns, coastal rocks with halophilic vegetation, vegetation of inland rocks and cliffs, and other very localized plant communities. Here, we draw up a general panorama of the terrestrial biodiversity of the SNR and briefly present the plant communities, which are the basis of the site's biodiversity, by determining the range of possible ecological niches for the various groups of species.

3.2.1. Terrestrial biodiversity

Biodiversity is a multi-faceted concept and it should be emphasized that the 'deification' of the number of species, as promoted by ecologists in the mid-20th century, is now largely outdated (Sala and Knowlton, 2006; Boudouresque, 2014b). Nevertheless, taxonomic diversity is still an important metric to obtain a first estimate of the biogeographical singularity of a territory and its functional complexity. For the SNR, the level of knowledge of taxonomic inventories is very heterogeneous between taxa, and while vertebrates and vascular plants are, as is usually the case, the best known, invertebrates, lichens, bryophytes and fungi remain largely unknown.

Of the 108 native species of regular breeding birds and established colonizers present in Corsica (Thibault, 2006), 50 species occur in the SNR, i.e. 46 % of the whole insular avifauna. The wintering species of birds were inventoried by Martin *et al.* (1988), and the diversity of birds is relatively low. Three species of seabird nest in the SNR: the Mediterranean shag *Phalacrocorax aristotelis desmarestii*, the yellow-legged gull *Larus michahellis* and the osprey *Pandion haliaetus* (see below) (Antona *et al.,* 1981a; Guyot, 1990; Thibault and Delaugerre, 1992). The rare Audouin's gull *Ichthyaetus audouinii* breeding in the Gulf of Portu regularly visits the SNR. Islets like Gargalu host colonies of the pallid swift *Apus pallidus*. The peregrine falcon *Falco peregrinus* is relatively abundant, probably feeding on gulls and migratory birds passing through the reserve. Passerines such as *Sylvia cantillans, S. sarda, S. undata* and *Serinus corsicana* and *Muscicapa striata tyrrhenica* thrive in the *maquis,* while *Parus* spp. and *Sylvia atricapilla* are present in holm oak *Quercus ilex* groves (Thibault and Delaugerre, 1992). The golden eagle *Aquila chrysaetos* is well present in Corsica, with at least 32 couples (Torre, 1995); while not nesting in the SNR, this area is undoubtedly part of its hunting territory (Thibault, 1983). The endangered bearded vulture *Gypaetus barbatus* also sometimes visits the SNR.

Concerning the mammalian fauna, eight out of the 22 species of Corsican bats are present at Scàndula (Noblet, 1989; Faggio, 1992; Rist, 2015): *Eptesicus serotinus, Hypsugo savii, Myotis emarginatus,* *Nyctalus leisleri, Pipistrellus pipistrellus, Plecotus austriacus, Rhinolophus hipposideros* and *Tadarida teniotis*; six of these species were recorded at Gargalu island in spring 2014 (Rist, 2015). The main limiting factor for bat fauna is probably the lack of water in summer, but other surveys should be undertaken in the inner part of the reserve to obtain a better picture of its diversity. All the other mammals observed at Scàndula, originally absent from Corsica, were introduced there by humans (Vigne, 1992): European hedgehog *Erinaceus europaeus*, weasel *Mustela nivalis*, red fox *Vulpes vulpes*, wood mouse *Apodemus sylvaticus*, house mouse *Mus musculus*, black rat *Rattus rattus*, Etruscan shrew *Suncus etruscus* and lesser white-toothed shrew *Crocidura suaveolens.* The wild boar *Sus scrofa* (in fact a feral pig) is common. In addition, goats abandoned in the 20th century by shepherds returned to the wild (feral goats) (Antona *et al.,* 1981a; Thibault and Delaugerre, 1992).

Twelve species of amphibians, geckos and lizards have been censused (Delaugerre, 1983). While the tortoise *Testudo hermanni* is very rare at L'Elbu, *Euproctus montanus, Discoglossus sardus, Tarentola mauritanica* and *Podarcis tiliguerta* are particulary abundant.

Knowledge of the terrestrial invertebrates is very disparate from one group to another: few data exist for snails (Real-Testud and Real-Testud, 1997), while almost nothing is known about isopods, collembola or earthworms for example, and more generally for the soil microfauna which is a key element for ecosystem services and act as indicators of soil quality (e.g. Barrios, 2007). Twenty-three species of ants were recorded in the SNR, including the islands and islets (Delaugerre and Casevitz-Weulersse, 1986; Casevitz-Weulersse, 1987, 1992); 64 species of Chalcidoidea (parasitic Hymenoptera) (Rasplus, 1992); 56 species of Lepidoptera (Cocquempot, 1992). One hundred and thirty-eight species of spiders divided into 33 families were identified during a field trip (Tiberghien *et al.,* 1993), but a survey focused on islands and islets has brought to eight other species (Ponel, 2015), including one of the genus *Haplodrassus*, new to science but apparently fairly widespread in southern Europe. Among the remarkable spiders of these small islands, let us cite *Gibbaranea bituberculata* found at Gargalu and which seems new to the fauna of Corsica, as well as the endemic Corsican *Spermophorides simoni* (islet of Cala Maiora) and *Euophrys luteolineata* (Gargalu Island) which was known only by the type described by E. Simon in 1871. Concerning Coleoptera, only partial inventories have been made which have identified around sixty species per field mission (Ponel, 1989; Cocquempot, 1992). Tiberghien *et al.* (1993) estimate that there are at least a hundred species of beetles in the reserve, but there are probably ten times more according to Philippe Ponel (pers. comm.)! Some interesting beetles are endemic to Corsica such as *Asida christinae*, to Corsica-Sardinia such as *Netocia sardea,* or to Corsica and Provence and the French Riviera such as *Crypticus gibbulus*; and some of them have recently been discovered on certain islets of the SNR by Ponel (2015) (Fig. 9).

Knowledge of the flora of the SNR is also rather heterogeneous. About 710 native vascular plants (angiosperms, gymnosperms and ferns), i.e. a third of the floristic richness of Corsica (2 153 species and subspecies), have been inventoried in the SNR (Frédéric Médail, unpublished data, December 2020), in this terrestrial area of only 900 ha. But these censuses often date from the past (Conrad, 1980, 1983; Gamisans, 1988, 1995) and they should be updated for most of the reserve area, except the islands and islets (Médail *et al.,* 2019; Médail and Pavon, 2021). This rich flora is characterized by the presence of many endemic plants, sometimes locally abundant (eg. *Armeria soleirolii, Erodium corsicum, Limonium corsicum, Seseli praecox*) or rare species (e.g. the ferns *Asplenium marinum* and *Cosentinia vellea*) (Fig. 10).

Figure 9. Two endemic beetles located on the small islands of the Scàndula Nature Reserve (SNR): **Left**: *Asida christinae,* restricted to western Corsica and occuring on Garganellu Islet. **Right**: *Smaragdina ferulae*, a Corso-Sardinian endemic Chrysomelidae occuring on Gargalu Island. Scale bar: 1 mm. After Ponel (2015), Photos © Philippe Ponel, courtesy of the author.

Figure 10. **Left**: *Armeria soleirolii* (Plumbaginaceae). **Right**: *Erodium corsicum* (Geraniaceae). Scàndula, May 2014. Photos © Frédéric Médail.

Data on the bryoflora are much sparser, and the only detailed study indicates 57 species in the L'Elbu sector (Hébrard, 1988), i.e. only 9.7 % of the bryophyte flora of Corsica which currently includes 587 species, among them 424 mosses, 160 liverworts and three hornworts (Hugonnot, 2019). Hébrard (1988) estimates that the bryoflora of the SNR is relatively poor, no doubt because of the scarcity of wet biotopes favorable to mosses and especially to liverworts. However, he highlights the presence of ten bryophyte species that are very rare elsewhere in Corsica and in mainland France. Data on fungi, lichens and lichenicolous fungi are unfortunately almost entirely lacking (Fig. 11), but a recent survey on fairly similar thermo-Mediterranean environments near Ajacciu demonstrates the value of carrying out in-depth inventories in these coastal biotopes (Gonnet and Gonnet, 2020).

3.2.2. The diversity of **maquis** *and forest ecosystems*

Tree and shrub vegetation is dominant in the territory of the SNR, and several types of forests and matorrals (maquis and shrublands) have been defined there. Some matorrals, close to the sea and subject to more or less strong marine influence, harbour a significant number of halophilic or haloresistant plants, while in the more inland areas of the SNR, dense *maquis* and more rarely maturing forest are thriving.

1) Forests and high *maquis*. At the bottom of certain small valleys, on relatively thick soils, there are dense oak groves with holm oak (*Quercus ilex*) which reaches 8 to 15 m in height, associated with the strawberry tree (*Arbutus unedo*), the tree heather (*Erica arborea*), the green olive tree (*Phillyrea latifolia*) and the flowering ash (*Fraxinus ornus*) (Fig. 12). This is the most mature forest stage in the SNR, and its maturation continues due to the absence of significant disturbances (fires) for decades (Fig. 13).

Figure 11. Examples of taxa poorly known in the Scàndula Nature Reserve. **Left**: the rich lichen flora of shaded rocks subjected to salt sea spray. *Rocella* sp. plur. (left and right of the photo), *Xanthoria calcicola* (orange lichen) and *Ramalina requienii* (whitish lichen, top of the photo). **Right**: the woodlouse (terrestrial isopod) *Porcellio orarum vizzavonensis*, endemic to Corsica and Sardinia, common on several islands and islets of the SNR; Gargalu Island, October 2020. Photos © Frédéric Médail.

Pre-forest matorrals and high *maquis*, of similar structure and floristic composition, are very common and in the process of extension in the SNR. In these thermophilic formations, 3 to 7 m in height, we can distinguish: **(i)** a high *maquis* with *Arbutus unedo* and *Erica arborea*; **(ii)** a high *maquis* with *Phillyrea latifolia*; **(iii)** a high *maquis* with *Pistacia lentiscus* and *Phillyrea latifolia,* characterized by the presence of *Clematis cirrhosa* and *Aristolochia tyrrhena*; *Myrtus communis* and *Viburnum tinus* are frequently present there. **(iv)** Other rarer types of high maquis have been observed (Bioret *et al.,* 2008): one with wild olive (*Olea europaea* subsp. *europaea*) near Punta Palazzu, the other with the cade juniper (*Juniperus oxycedrus*).

On the rocky slopes overlooking the sea, the *Juniperus phoenicea* subsp. *turbinata* community has become denser since the work of Gamisans and Muracciole (1984), so that some relatively sheltered coastal slopes and valleys are now covered with enclosed and tall juniper woodlands, which probably constitute the likeliest potential vegetation in these areas. There is also a small coastal forest with *Pinus halepensis*, which regenerates spontaneously in the area of Cala di Ficaccia. Although *P. halepensis* is considered as allochthonous in Corsica, because it is occasionally planted by man (Reille, 1992), the native nature of the population at Scàndula is possible because of its ecology and its remote location; but only a paleoecological or phylogeographical study could clarify this intriguing question.

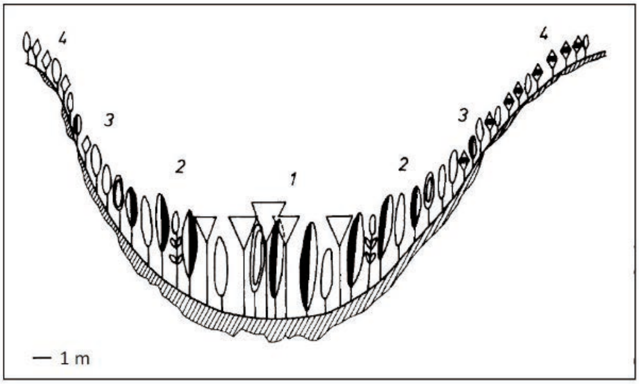

Figure 12. Schematic cross-section showing the structure of tree and shrub vegetation within the SNR, in a small valley and on the surrounding slopes. 1: sclerophyllous forest with *Quercus ilex, Phillyrea latifolia* and *Arbutus unedo*. 2: high *maquis* with *Erica arborea* and *Arbutus unedo*. 3: low *maquis* with *Erica arborea* and *Cistus* sp. plur. 4: low shrublands with *Cistus creticus* subsp. *corsicus* and *Helichrysum italicum*. After Gamisans and Muracciole (1984).

Figure 13. **Left**: forest and high *maquis* with *Juniperus phoenicea* subsp. *turbinata*, *Olea europaea, Erica arborea* and *Arbutus unedo*, Scàndula nature reserve. **Right**: an elderly individual of *Arbutus unedo* in the high *maquis*, near the Genoese tower of L'Elbu; the multi-stem arrangement denotes earlier cutting at the base of the trunk; October 2020. Photos © Frédéric Médail.

Finally, riparian forests are very rare, due to the absence of permanent streams in the SNR. There are, however, a few fragments of a riparian forest with *Fraxinus ornus* in valley bottoms, and *Vitex agnus-castus* has been observed, forming a gallery along the Canalette stream (L'Elbu), in a back-beach location (Bioret *et al.,* 2008).

(2) Low to medium *maquis.* Various types of low or medium-height *maquis* (less than 2-3 m high) have been identified in the SNR, depending on their composition and structure, but also on their coastal or more inland location (Gamisans and Muracciole, 1984; Médail *et al.*, 2019).

The low coastal *maquis* with *Pistacia lentiscus* and *Smilax aspera* is an often anemomorphic shrub formation, not exceeding two meters in height, but with very high cover. It is located on dry slopes and on stony soils; in situations very exposed to the southwest wind (in Corsican: *Libecciu*), it can reach 80 to 100 m above sea level.

The *Euphorbia dendroides* and *Pistacia lentiscus maquis*, associated with the wild olive *Olea europaea*, is well developed on the rocky slopes overlooking the sea, especially on the island of Gargalu (Fig. 14). Compared to the low *P. lentiscus maquis*, the generally slightly less dense structure of this habitat can allow its coexistence, on very stony substrate, with the low scrub of *Teucrium marum* and *Genista corsica*. On the cliffs and rocky ledges, the low *Euphorbia dendroides* scrub is even more sparse and *E. dendroides* dominates *P. lentiscus* as on the northern end of L'Elbu. But on the whole, with the abandonment of sylvo-pastoral uses, the *P. lentiscus maquis* is progressing in many of these habitats to the detriment of *E. dendroides*. This dynamic is clearly visible on the eastern slope of Gargalu Island.

The halo-nitrophilic *maquis* with *Malva subovata* (= *Lavatera maritima*) and *Pistacia lentiscus* is only present on the stony slopes of Gargalu Island, especially on the western one, which is particularly windy and subject to the presence of nesting gulls. The dynamics of the vegetation and the extirpation of feral goats, which were exerting strong grazing pressure (Bioret, 2002) led to the progression of the meadow with *Brachypodium retusum* and *Malva subovata* towards the current low *maquis.*

Figure 14. Two very contrasting aspects of the islands of the Scàndula Nature Reserve. **Left**: the low coastal *maquis* with *Pistacia lentiscus* competing with the *Euphorbia dendroides* matorral on the eastern side of Gargalu Island; at the top, the Genoese tower. **Right**: the imposing *faraglione* of Cala Maiora, 60 m high, an islet *a priori* inhospitable but which harbours about fifty species of vascular plants and the endemic Corsican spider *Spermophorides simoni*. October 2020, Photos © Frédéric Médail.

The low *maquis* with *Erica arborea* is a transition habitat between *Cistus* shrublands and the high *maquis*, present on shallow soils, but it is in the process of disappearing through the progressive dynamics of the sclerophyllous vegetation. Finally, the low coastal wind-formed *maquis* with *Juniperus phoenicea* subsp. *turbinata* and *Olea europaea* is found in sites exposed to relatively high temperatures, such as at Cala di Muretta (Bioret *et al.,* 2008).

(3) *Cistus* shrubland. The high *Cistus* shrubland with *Cistus creticus* subsp. *corsicus* dominant is located on the fringes of low maquis whereas the low *Cistus* shrubland with *Cistus monspeliensis* thrives on more degraded soils. These shrublands are located at or near the former sites of human occupation (threshing floors, crops). Following the natural dynamics of the vegetation and in the absence of fire, they are often enriched by species of low or high maquis and they have clearly declined in surface area over the past fifty years (Bioret *et al.,* 2008).

(4) Low scrubs. Two main types can be distinguished (Gamisans and Muracciole, 1984; Gamisans, 1988). **(i)** The semi-halophilic littoral scrub with *Thymelaea hirsuta* and *Helichrysum italicum* is located between the halophilic vegetation belt of rocks with *Crithmum maritimum* and *Limonium corsicum* (below) and the *maquis* dominated by *Pistacia lentiscus* (above). In the area of Scàndula, it is typical and well represented on Gargalu Island where only *Thymelaea hirsuta* is to be found. This 40-50 cm high formation occupies the gentle slopes (20° through 60°) on earthy substrate, up to about 50 m above sea level. In addition to *Thymelaea hirsuta*, this scrub is structured by *Euphorbia pithyusa* and *Helichrysum italicum*. It can be considered as a long-lasting habitat, not seeming to evolve towards maquis with *Pistacia lentiscus*. **(ii)** The low scrub (30-50 cm high) with *Genista corsica* and *Teucrium marum* occupies rocky bars or slabs, and areas with very eroded and stony soils. It is also characterized by the presence of *Stachys glutinosa* and *Rosmarinus officinalis*. It has various variants including a halophilic one with *Daucus carota* gr. *gummifer* occupying the earthy-rocky ground near the sea (Gamisans and Muracciole, 1984), and an internal variant on the summit ridges of the SNR (Bioret *et al.,* 2008).

3.2.3. Other vegetation types

(1) Littoral vegetation of rocks and cliffs. The coastal border of the SNR is essentially formed by an impressive maze of rocks and cliffs, subject to marine influences sometimes to an altitude of over 100 m in the sites exposed to the *Libecciu* wind. The lower part of the cliffs, regularly sprayed by sea spray, is home to a paucispecific community characterized by *Crithmum maritimum*, *Limonium corsicum* and *Erodium corsicum*. The rocks and cliffs of the SNR frequently harbour in the crevices and on the patches of coarse stones a very original haloresistant community, characterized by two taxa of high heritage value, *Armeria soleirolii* and *Seseli praecox* (Fig. 15), which replaces the previous community at around 4-5 meters above sea level. There are sometimes small vernal pioneer grasslands, present on sandy patches and pits and composed of annual species, notably the grasses *Catapodium marinum* and *Parapholis incurva*. This community can be observed in a few islets (Garganellu, Palazzinu), with other halotolerant lawns dominated by *Sagina maritima* (Garganellu island) or *Spergularia marina* (Palazzinu islet) (Médail *et al.,* 2019). Finally, a few deep cracks in the rocks, which are never exposed to the sun because they are located in sea cliffs facing north (especially on the northeast coast of Gargalu), are home to a very rare community characterized by the Atlantic-Mediterranean fern *Asplenium marinum*.

Figure 15. The haloresistant community on littoral rocks and cliffs of the Scàndula Nature Reserve, characterized by *Armeria soleirolii* and *Seseli praecox* (green), together with the nitrophilic lichen *Xanthoria calcicola* (orange). Gargalu Island, May 2014. Photo © Frédéric Médail.

(2) Meadows and thickets more or less nitrophilic and halophilic. Various types of nitrophilic and halophilic grasslands, meadows and thickets are present on the slopes and the cliff ledges close to the sea in the SNR. They generally correspond to the nesting sites or resting places of the yellow-legged gull *Larus michahellis*.

A variety of ruderal grasslands have been recorded, in particular on the islands and islets of the SNR such as Gargalu Island (Médail *et al.*, 2019): **(i)** a halophilic community with *Atriplex prostrata* on the flats very enriched in guano; **(ii)** a semi-halophilic community with *Senecio transiens* and *Catapodium marinum* or *Mesembryanthemum nodiflorum*; **(iii)** a semi-halophilic community with *Mesembryanthemum nodiflorum* on bare ledges at the foot of rock walls or in sandy basins; **(iv)** a semi-halophilic community with *Fumaria bicolor* and *Lotus cytisoides*, occasional in the gaps within the low *Pistacia lentiscus maquis*; **(v)** a community with *Lobularia maritima* and *Erodium chium* which occupies large areas on Gargalu Island, in the sectors previously occupied by low scrubs and where the presence of gulls has led to its decline in favour of halo-tolerant and nitrophilic species (Médail *et al.,* 2019; Médail and Pavon, 2021).

A taller (50 to 80 cm) and dense herbaceous community, dominated by a *Daucus carota* gr. *gummifer*, associated with *Dactylis glomerata* subsp. *hispanica, Jacobaea maritima* and *Lotus cytisoides*, is present on earthy slopes, in particular cool and windy corridors, and on the ledges close to the sea, in particular at Gargalu Island and at a few sites at Sulana Bay. A facies with *Matthiola incana* is present on the western slope of the northwestern end of Gargalu Island (Médail and Pavon, 2021).

The halo-phosphato-nitrophilic thicket with *Malva arborea* (= *Lavatera arborea*) and *Fumaria bicolor* has been found on a few islets (notably Palazzinu), in areas highly frequented by gulls which enrich the soil with guano (Médail *et al.,* 2019).

Other more localized communities of herbaceous wastelands have been reported in the SNR: **(i)** a community with *Galactites tomentosus* on Gargalu Island, in areas which are a little less mesophilic and sunnier than those occupied by *Daucus carota* (Médail *et al.,* 2019); **(ii)** a community with *Polygonum scoparium* and *Dittrichia viscosa* on the back-dune of L'Elbu Cove (Bioret *et al.,* 2008).

(3) Plant communities of inner cliffs and rocks. The plant communities of rocks and cliffs far from the sea are relatively poorly represented in the SNR, in particular because the rocks (rhyolites) do not offer the narrow slot systems favorable to this type of vegetation, according to Gamisans and Muracciole (1984). However, several very localized rupicolous communities, characterized by a variety of ecological conditions, can be observed. **(i)** A community with *Adiantum capillus-veneris,* dwelling on a few shaded and weeping walls. **(ii)** A community with *Cymbalaria aequitriloba* in shelters (often *tafoni*), very shaded and humid, at L'Elbu and Gargalu Island (Frédéric Médail, unpublished obs., October 2020). **(iii)** A community with *Polypodium cambricum* and *Umbilicus rupestris* in mesophilic conditions. **(iv)** A terricolous community with *Selaginella* *denticulata* and *Sagina subulata* in areas with little sun and on lastingly wet soil. **(v)** A community with *Cheilanthes marantae,* which seems very localized in the SNR, present at the bottom of the rock slabs under thermo-xerophilic conditions. **(vi)** A community with *Dianthus sylvestris* and *Asplenium obovatum* subsp. *billotii*, in fairly warm and sunny cliff crevices, where *Seseli praecox* can be found in non-halophilic conditions (Gamisans and Muracciole, 1984). **(vii)** A community of slabs or rock bars with *Sedum caeruleum*. **(viii)** A community with *Biscutella didyma* on steeply sloping screes that are very hot and dry in summer.

(4) Other, very localized, plant communities. Several communities, very localized and of limited extension, have been recorded in the SNR. These communities are not without interest because they form the basis of an ecosystem that often includes communities of invertebrates that are not found elsewhere. On L'Elbu beach, a few *banquettes* of dead leaves of *Posidonia oceanica* cast ashore, with *Euphorbia peplis*, have been reported; the dune is home to a psammophilic community with *Helichrysum italicum, Eryngium maritimum* and *Glaucium flavum*, and in the sandy back dune, a little further inland, one observes a small community with *Corrigiola telephiifolia* subsp. *imbricata* (Frédéric Médail, unpublished obs., October 2020). Rare wet spots along the coast are home to a *Juncus acutus* community, the largest being located behind L'Elbu beach. Finally, a riparian community with *Osmunda regalis, Carex microcarpa* and *Hypericum hircinum* is scattered along some semi-permanent brooks (L'Elbu, Canalette, Gattaghja) (Gamisans and Muracciole, 1984).

There is also a certain diversity of dry grasslands with annual species which typically develop over a few square meters at most, in mosaic with low maquis or scrubs, or in sparsely vegetated areas on thin and sandy, highly filtering soils. Two main sets of grasslands have been identified: **(i)** with *Plantago bellardi* and *Vulpia ciliata*; **(ii)** with *Vulpia myuros* and *Crassula tillaea*. On thicker soils, which retain water better, a grazed grassland with *Trifolium subterraneum* and *Bellis perennis* has been reported (Gamisans and Muracciole, 1984). In view of the phytoecological *relevés* of these authors, it is also possible to identify the presence of a hygrophilous grassland with *Mentha pulegium* and *Lotus angustissimus*. It should be noted that these annual grasslands have been little studied within the SNR, and more in-depth phytoecological analyses are necessary.

3.2.4. Ecological singularities of small islands and islets of Scàndula

Twenty-three small islands and islets harbouring vascular plants are present within the perimeter of the SNR, among the thirty that exist between Galeria and U Portu (Médail *et al.,* 2019). The small islands and islets of the Mediterranean are most often characterized by a strong originality in the structure and functioning of terrestrial communities and in their biodiversity (Médail, 2017). The above inventory of plant communities in the SNR illuminates this aspect well. We note the uniqueness of several plant communities located on the largest island, Gargalu (22 ha): the *maquis* with *Malva subovata* and *Pistacia lentiscus* only occurs there, and it is the main site for a variety of halo-nitrophilic communities. Let us also mention the existence of the halo-nitrophilic thicket with *Malva arborea* on certain islets very frequented by sea birds.

These resting or feeding areas for the yellow-legged gull *Larus michahellis* and, to a lesser extent, the Mediterranean shag *Phalacrocorax aristotelis desmarestii,* are characterized by substrates whose chemical composition is greatly altered by high concentrations of P, K, Mg ions and of soluble salts (García *et al.,* 2002). Combined with the regular trampling of birds and the supply of propagules exogenous to the island, these recurrent contributions within very limited areas lead to clear alterations in the structure and composition of small island and islet communities (e.g. Vidal *et al.,* 2000), by promoting the increase of salt-tolerant nitrophilic ruderal plant species (so-called halo-ornithocoprophiles). These resting places are found in particular on the Gargalu and Garganellu islands, the Porri islet (outside the SNR) and Palazzu. For entomofauna, it should be noted that on Garganellu Island, the endemic beetle (Tenebrionidae) *Asida christinae* was only found in the part of the island where the droppings of these birds were most abundant (Ponel, 2015). These areas are also characterized by the very great abundance of an endemic Corsican-Sardinian woodlouse, *Porcellio orarum* subsp. *vizzavonensis* (Fig. 11): each tuft of *Limonium corsicum* houses between 10 and 50 individuals (Frédéric Médail, unpublished obs., October 2020).

Elsewhere, the table-like top part of Porri islet, with a vegetation dominated by *Malva arborea*, strongly impacted by gulls, is precisely the area where insects are the most numerous. This fact is only seemingly paradoxical because gulls play an important role in the food chain of small islands, owing to the supply of nutrients from the marine environment (Polis and Hurd, 1995). This supply is important for saprophagous and coprophagous arthropods, and also for predators (spiders), especially in islets with scarce plant cover and where trophic resources are limited. This is precisely the case for most of the islets of the SNR, where the nocturnal activity of the geckos is also concentrated in these areas with guano, rich in arthropods (Michel Delaugerre, pers. comm.). These original trophic networks induced by the presence of gull colonies deserve to be studied more in-depth.

The 23 islands and islets of the SNR include a total of 174 species and subspecies of native vascular plants, i.e. a quarter of the floristic richness of the SNR, 87 % (n = 152) of which are present on Gargalu Island (Médail *et al.,* 2019; Médail and Pavon, 2021). The plant richness of Gargalu is significantly higher than that expected on the basis of island biogeography theory (regression model log area / log richness). It is important to point out that unlike many Mediterranean islands, the impact of invasive non-native species has so far been negligible: a single individual of a naturalized exotic taxon (*Opuntia ficus-indica*) has been recorded, on the Catò Est islet, which highlights the good general 'ecological state' of the terrestrial environment.

As far as vertebrates are concerned, the major interest is also concentrated on the island of Gargalu. This island accomodates 14 species of nesting birds (certain or probable), including Marmoras's warbler *Curruca sarda* (= *Sylvia sarda*) and the dartford warbler *Curruca undata* (= *Sylvia undata*), two species listed in Annex I of the European Union Birds Directive, and whose presence on small Corsican islands is remarkable (Faggio, 2015). For herpetofauna, Delaugerre (1986b) reported, on these islands and islets, four species of saurians (the European leaf-toed gecko *Euleptes europaea*, the Fitzinger's algyroides *Algyroides fitzingeri*, the Tyrrhenian wall lizard *Podarcis tiliguerta*, and the common wall gecko *Tarentola mauritanica* which disappeared one year later) and one ophidian, the green whip snake *Hierophis viridiflavius* which is only present at Gargalu (observed again in October 2020), just like Fitzinger's algyroides. The most commonly encountered species, present on 16 islets, is the European leaf-toed gecko, an endemic species of the Central Mediterranean able to survive on the smallest islets in low-nutrient habitats (Delaugerre and Corti, 2020). This gecko shows locally a high inter-population variability. An interesting observation is that its populations from the islet of Porri show a tendency to gigantism, while those of Gargalu Island exhibit, on the contrary, a marked dwarfism, compared to the populations of the mainland (Delaugerre, 1986b; Delaugerre and Casevitz-Weulersse, 1986; Delaugerre and Cheylan, 1992). These aspects are characteristic of the famous insularity syndrome (Blondel, 1995).

3.2.5. Overall dynamics of terrestrial vegetation

Few regional paleoecological data are available to correctly estimate the potential forest vegetation of Scàndula, that is to say that present after the last glacial maximum of Würm (LGM, ca. 20 000 years BP). According to the palynological studies conducted by Maurice Reille in the Galeria region (Fango valley site), the potential forest vegetation during the climatic optimum of the Holocene (Atlantic palynozone, between ca. 7 500 and 4 800 years BP) was a forest, or a high *maquis*, dominated by the tree heather *Erica arborea* and the strawberry tree *Arbutus unedo*. In Western Corsica, their altitudinal range was much greater compared to that of today since this evergreen forest occupied an area between the coast and 1 500 m above sea level. The holm oak *Quercus ilex* was, then, confined to rupicolous situations and its place in the forest vegetation was negligible (Reille, 1988, 1992). It is only with clearings and the development of pastoralism that the holm oak has been able to spread, because it is more tolerant and adaptable in the face of disturbances such as fire and overgrazing than the tree heather and the strawberry tree.

Obviously, the knowledge relating to the prehistoric and historical human influence (see above) suggests that the modifications of the landscapes and the alteration of the arborescent or shrub ecosystems must have been extensive because of regular pastoral and agricultural activities over centuries (Ruggieri, 1981; Alfonsi and Gianetti, 1983; Gianetti, 1986). The Galeria region was a privileged area for winter grazing by herds from the Niolu and there were six sheepfolds in the L'Elbu area at the end of the 19th century; the presence of 13 threshing floors for wheat and barley in the SNR also shows that fairly flourishing crops were cultivated, which required a great effort of in-depth deforestation ('*u diceppu*'), with double clearing (Gianetti, 1986), or a less demanding practice, quick slash and burn ('*u bichjetu*'). In addition, the manufacture of charcoal required large quantities of wood which was slowly consumed in a circular area, the '*carbonara*'.

On Gargalu Island, the absence of *Quercus ilex, Erica arborea, Arbutus unedo* and *Phillyrea latifolia*, however common on the mainland of the SNR, is no doubt explained by the fuelwood requirement associated with the building of the Genoese tower, then by regular intensive grazing, because the island was famous for its pastures, so that ewes and their kids were taken there (Gianetti, 1986). On these islands and islets, the pervasive influence of sea spray, the violence of the wind, the recurring impact of nesting birds and the now very reduced thickness, or even absence, of the soils led to a much slower or even impossible ecological succession towards high *maquis*.

The territory of the SNR, apparently very natural and without human impact, is actually the legacy of uninterrupted agro-sylvo-pastoral pressures for millennia. But with almost no human impact for more than 50 years, the absence of wildfires and also much less pressure from grazing by cows and goats, the natural dynamics is accelerating. The diachronic studies of the vegetation of the SNR show the rapid progression of the vegetation cover between 1983 and 2007 (Gamisans, 1988, 1995; Bioret *et al.,* 2008, 2009) (Fig. 16, 17). The main phenomenon is the doubling of the surface area of the high *maquis,* with the maturation of the latter in the areas where it was already present. The current dynamics seems to be leading towards high *maquis* with holm oak *Quercus ilex*, but will we ultimately witness a reconstitution of the holm oak forest, or rather of the potential forest with *Erica arborea* and *Arbutus unedo* highlighted by paleoecological studies? (Reille, 1988, 1992). The low *maquis* has also progressed, due to the maturation of the *Cistus* shrublands and the colonization of part of the rocky areas hitherto bare (Bioret *et al.,* 2008, 2009). On the other hand, we are witnessing the virtual disappearance of pure *Cistus* shrublands and low shrublands in favour of low *maquis* on rocks. The clear decline in plant communities of more or less bare rocks and screes, in the inner part of the SNR, is explained by the colonization of rocky slopes by species from the low *maquis,* and we are witnessing a clear inversion, of a magnitude of five, of surfaces covered by these two communities.

Figure 16. Thermo-Mediterranean coastal *maquis* with *Juniperus phoenicea* subsp. *turbinata* and few *Euphorbia dendroides* on the rhyolitic rocks located north of L'Elbu Marina; October 2020. Photo © Frédéric Médail.

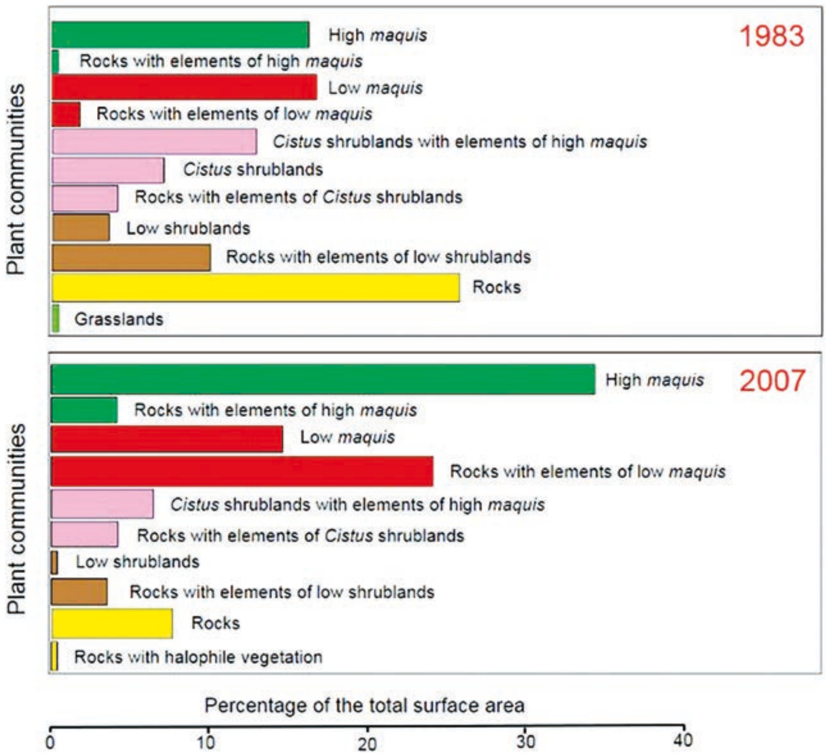

Figure 17. Dynamics of the relative surface area covered by the main types of vegetation in the terrestrial part of the Scàndula Nature Reserve (SNR). **Top**: results obtained from the mapping carried out in 1983 (Gamisans and Muracciole, 1984). **Bottom**: assessment resulting from the mapping carried out in 2007. From Bioret *et al.* (2008, 2009), adapted.

3.3. The marine ecosystems

3.3.1. Macroalgae

Macroalgae constitute the traditional name for a polyphyletic ensemble of organisms belonging to two distinct kingdoms, Archaeplastida (Ulvophyceae – green algae – and Rhodobionta – red algae) and Stramenopiles (Phaeophyceae – brown algae) (Boudouresque *et al*., 2011; Boudouresque, 2015; Boudouresque *et al.,* 2015a; Verlaque *et al.,* 2015).

In Corsica, 505 taxa and stadia of macroalgae have been reported (Boudouresque and Verlaque, 1976; Boudouresque and Perret, 1977; Boudouresque and Verlaque, 1978; Verlaque and

Boudouresque, 1981; Boudouresque and Perret-Boudouresque, 1987; Verlaque, 1989). Most of them (454) are present in the region of Galeria (including the SNR) (Verlaque, 1988a, 1988b, 1990a, 199b; Rodriguez-Prieto *et al.,* 1993). Scàndula constitutes the only known locality of *Cystoseira jabukae* outside the Adriatic Sea, and the northernmost locality of the rare *C. funkii* (Verlaque *et al.,* 1999a). Rodriguez-Prieto *et al.* (1993) added *Chaetomorpha pachynema* and *Halymenia trigona* to the Corsican flora. This makes Scàndula one of the most species-rich regions in algae in the Mediterranean and even in the world (Boudouresque *et al.,* 1992a). Obviously, it is not easy to distinguish between intrinsic species richness and the fact that it is a particularly well explored region.

Species of the genus *Cystoseira* (*sensu lato*) and *Sargassum* are conspicuous in that they are canopy-forming and form marine forests. *Cystoseira* species are not only organisms as complex as flowering plants, rather than primitive plants ('algae') as earlier authors believed - they have a trunk, leaves, a sap-conducting apparatus, etc. - but they can also be very long-lived, thus justifying the fact of being now assimilated to trees, which form forests (Ballesteros *et al.,* 2009; Boudouresque *et al.,* 2015, 2017a). It was while working on the exceptional *Cystoseira montagnei* (as *C. spinosa*) *and C. zosteroides* forests of the SNR that Ballesteros *et al.* (1998, 2009) discovered this unexpected longevity.

In most parts of the Mediterranean, the *Cystoseira* (*sensu lato*) and *Sargassum* forests that, in the 19th and early 20th century, carpeted the subtidal reefs from the sea surface down to 40 to 50 m depth, have severely declined. The main cause is overgrazing by the herbivorous sea urchin *Paracentrotus lividus*, due to the overfishing of its predator fish. This results in 'barren grounds', i.e. reefs covered with encrusting corallines, deprived of erect macroalgae and overloaded with sea urchins (Coma *et al.,* 2011; Agnetta *et al.,* 2015; Boudouresque *et al.,* 2017a; Melis *et al.,* 2019; Boudouresque and Verlaque, 2020). In many regions, *Cystoseira* and *Sargassum* species are not only functionally extinct (i.e. no longer building forests), but also locally extinct, as has occurred on the French Riviera and in French Catalonia (Thibaut *et al.,* 2005, 2015, 2016; Mannino *et al.,* 2020).

In contrast to most Mediterranean regions, lush *Cystoseira* forests still occur in the Scàndula marine reserve: *C. brachycarpa, C. crinita, C. montagnei, C. zosteroides*, etc. (Fig. 18) (Ballesteros *et al.,* 1998, 2009; Verlaque, 2013; Blanfuné *et al.,* 2016a ; Cheminée *et al.,* 2017). *Cystoseira crinita*, a species dwelling in shallow reefs, which is regionally or functionally extinct in French Catalonia and the French Riviera, is still common at Scàndula (Blanfuné *et al.,* 2016a). In addition to being vast and a beautiful sight for divers, which is meaningless from an ecosystem point of view (see e.g. Boudouresque *et al.,* 2015b, 2020a), the recent ecosystem-based approach showed that Scàndula's forests reach the highest score for the EBQI (Ecosystem-Based Quality Index) for shallow rocky reefs in the NW Mediterranean (Thibaut *et al.,* 2017). It is worth highlighting that it is in the SNR that Cheminée *et al.* (2017) showed their role as juvenile teleost nursery: *Cystoseira* forests hosted richer and three-fold more abundant juvenile assemblages than low communities dominated by Dictyotales and Sphacelariales (small and ephemeral brown algae) in the unprotected Calvi area (about 30 km north).

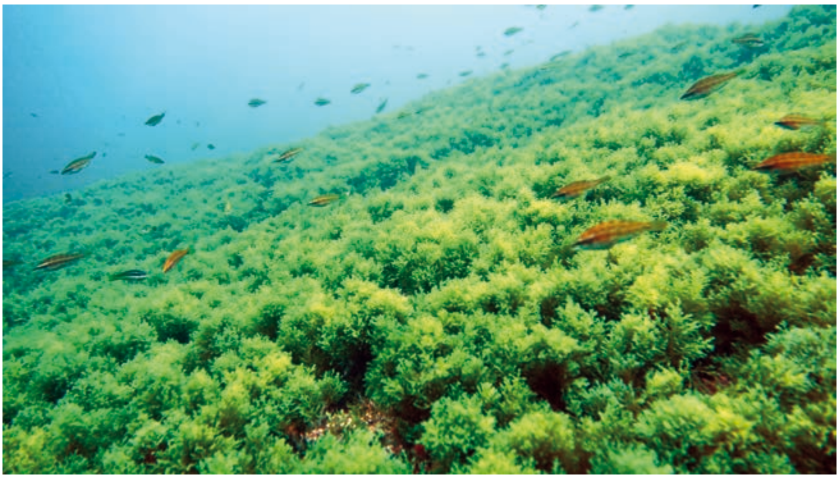

Figure 18. A *Cystoseira brachycarpa* forest. Punta Palazzu, 5-10 m depth, in 2017, Scàndula Nature Reserve. Such a seascape is today highly uncommon in the Mediterranean Sea. Photo © Adrien Goujard, GIS Posidonie (courtesy of the author).

Maps of *Cystoseira amentacea* and *C. compressa*, for each 20 m stretch of coast, i.e. on an almost metric scale, were produced between 1993 and 1996 (Meinesz *et al.,* 1999). It is worth emphasizing the incredible precision of these maps, unique in the Mediterranean. These maps (and others - see below) provide a valuable baseline for further comparisons. *Cystoseira amentacea* constitutes an almost continuous belt, just below the mean sea level (in the infralittoral fringe) all along the coastline of the reserve (Thibaut *et al.,* 2014).

Several species of macroalgae from Scàndula have been described as new taxa: *Acrochaetium virgatulum* var. *crassitrichum* (Verlaque *et al.,* 1977), *Peyssonnelia rara-avis* (Marcot and Boudouresque, 1977) and *Pseudolithophyllum cabiochae* (Boudouresque and Verlaque, 1978). The very rare *Cystoseira jabukae*, described from the Adriatic Sea and probably endangered, is present at Scàndula (Verlaque *et al.,* 1999a; Blanfuné *et al.,* 2013).

The CARLIT index (CARtography of LITtoral and upper-sublittoral rocky-shore communities) was proposed by Ballesteros *et al.* (2007) to assess the quality of water bodies, in the framework of the European Union (EU) Water Framework Directive (WFD). It is based on species from the infralittoral fringe (just below mean sea level) and the midlittoral zone (above the mean sea level), easy to sight and identify for non-specialist managers, such as *Cystoseira amentacea, C. mediterranea*, articulated corallines, *Ulva* and *Cladophora* green algae. The CARLIT index is today the most widely-used index in the Mediterranean, both in countries belonging to the EU and in others, such as Albania and Lebanon (e.g. Bermejo *et al.,* 2013; Nikolić *et al.,* 2013; Blanfuné *et al.,* 2016d; Torras *et al.,* 2016; Blanfuné *et al.,* 2017; Badreddine *et al.,* 2018; De la Fuente *et al.,* 2018; Grech *et al.,* 2019). As expected, the CARLIT index indicates, for the Scàndula area, a high quality of coastal water (Blanfuné *et al.,* 2017).

Unfortunately, at the turn of the 21st century, a beginning of decline of the forests of *Cystoseira* can be observed in Scàndula, with the appearance of overgrazing and barren grounds (Verlaque *et al.,* 1999b; Ballesteros *et al.,* 2002). Throughout the Mediterranean and around the world, these barren grounds, due to overgrazing by sea urchins, are the result of overfishing of sea urchin predatory fishes (e.g. Sala *et al.,* 1998a, 1998b; Coma *et al.,* 2011; Ling *et al.,* 2015). This means that, at Scàndula, the management of the artisanal fishery should be re-assessed.

3.3.2. Seagrasses

Eight species of seagrasses (marine Magnoliophyta) occur in the Mediterranean Sea: *Cymodocea nodosa, Posidonia oceanica, Ruppia cirrhosa, R. maritima, Zostera marina* and *Z. noltei* (Boudouresque *et al.,* 2009; Ruíz *et al.,* 2009) are native, whereas *Halophila stipulacea* and *H. decipiens* were introduced from the Red Sea *via* the Suez Canal and ballast water discharge, respectively (Por, 1978; Boudouresque, 1999a; Boudouresque *et al.,* 2009; Gerakaris *et al.,* 2020). *Ruppia cirrhosa* could be a synonym of *R. maritima* (but see Hartog and Triest, 2020). Only one seagrass species is present in the Scàndula nature reserve, *Posidonia oceanica*. A second one, *Cymodocea nodosa*, is present in the vicinity of the reserve, at Ghjirulatu (in the south) and at Galeria and Calvi (in the north).

Several types of *P. oceanica* meadows (‘*alghili*’ in Corsican) have been described: the plain meadow (the most common) (Fig. 19), the hill meadow, the striped meadow, the sugar loaf meadow, the tiered (or staircase) meadow, the undulating meadow and the *Posidonia* barrier reefs (Molinier and Picard, 1952; Boudouresque *et al.,* 1985, 2012, 2014; Bonhomme *et al.,* 2015). Barrier reefs are absent from the area, due to the exposed conditions (Rouanet *et al.,* 2020a). The striped meadow and the sugar loaf meadow, absent from the reserve area, are linked to warmer waters (Boudouresque *et al.,* 2012); in Corsica, the striped meadow has only been observed near Portivechju and Bunifaziu. Only two types of meadow are present in the reserve area: the plain meadow and the hill meadow; a third type occurs near Punta di u Ciuttone, north of the Gulf of Galeria, the tiered meadow (Boudouresque *et al.,* 1985, 2012).

It should be noted that two of the types of *P. oceanica* meadows, namely the hill meadow and the tiered meadow, have been described from the SNR, or its surroundings, in the framework of the research programmes piloted by the Scientific Council of the reserve (see below) (Boudouresque *et al.,* 1985, 2012).

Figure 19. A plain type *Posidonia oceanica* seagrass meadow at Gattaghja Cove, Scàndula Nature Reserve, June 2017. Photo © Nardo Vicente.

The **tiered meadow** develops on hard substrates with a relatively steep slope and descending bottom currents (during storms). Parallel strips of meadow, 0.5 to 3.0 m wide, shift up the slope against the current. Upstream of each step, plagiotropic (i.e. creeping) *P. oceanica* rhizomes advance at an average speed of 10 cm/year, whereas downstream, the current erodes the vertical part of the step (Fig. 20). At Punta di u Ciuttone, where this astonishing and rare type of *P. oceanica* meadow was discovered, on average several centuries are needed for a step to develop at the base of the slope, move up it completely, and finally be destroyed there by hydrodynamism (Boudouresque *et al.,* 2012).

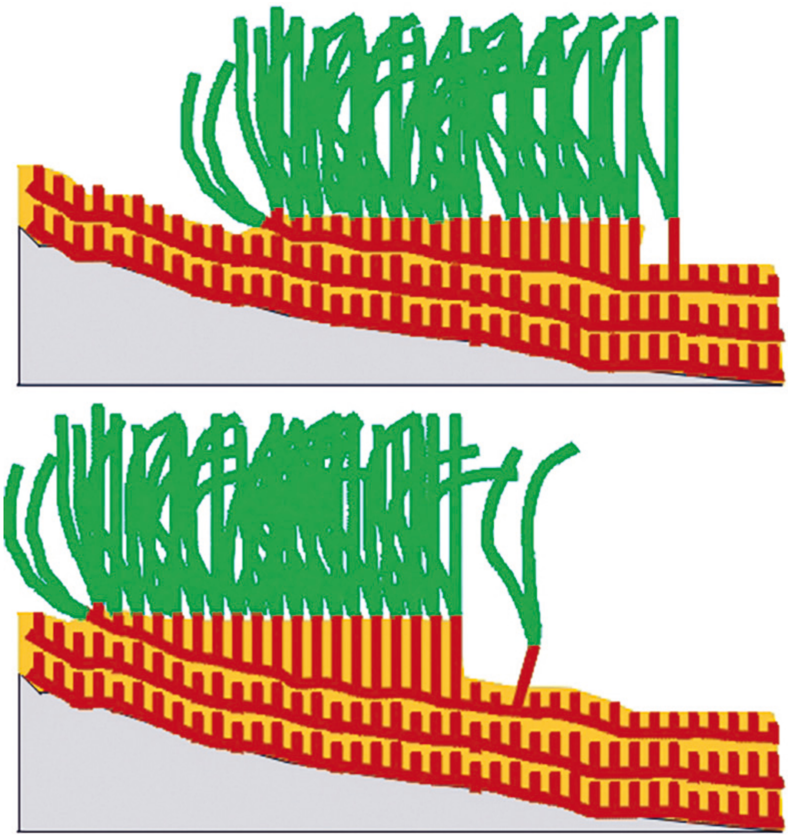

Figure 20. The tiered *Posidonia oceanica* meadow. A step (staircase) of *P. oceanica* (above) shifts up the slope (below: ~10 years later) and is eroded back by the bottom current. Drawing: Charles-François Boudouresque.

The **hill meadow** develops between 15 and 30 m depth, in sectors where there is high hydrodynamism (Fig. 21). This type of *P. oceanica* meadow was discovered near the mouth of L'Elbu Cove. In a hill meadow, *P. oceanica* cuttings produce 'hills' that grow higher and wider; the hills are surrounded by sand. When the hills grow higher, they become more exposed to hydrodynamism; at the summit, the sediment of the *matte* is poorly retained and the orthotropic (i.e. erect) rhizomes lose their hold; the exposed rhizomes are vulnerable and a kind of *intermatte* forms. Over time, the *intermatte* widens until the hill is entirely, or mostly, destroyed; the lifetime of a hill, between its initial formation and its destruction, is usually about one century. It seems that the destruction of a hill is not always complete and that a new hill can develop from the remains of a former hill (Boudouresque *et al.,* 1985, 1986a, 2012).

Figure 21. A hill type *Posidonia oceanica* meadow. Cavalaire (Provence, France), 8 m depth. Photo © Florian Holon, Andromède Océanologie (courtesy of the author).

In 1982, at the *Maison de la mer* in Galeria, Alexandre Meinesz and one of the authors (CFB) took part in a field mission to Scàndula. The objective was to measure the growth rate of the rhizomes of *P. oceanica*. But after a year of work, the experiment turned out to be a failure. One night, after casually loosening hundreds of scales (the bases of the leaves that persist on the rhizomes) from the rhizomes while moaning about a failed experiment, there was a flash of inspiration. There appeared to be cycles of thickness of the scales along the rhizomes (Fig. 22). What if these cycles were annual? In the early morning, after detaching thousands of scales, lepidochronology was born (Boudouresque *et al.,* 1983a; Crouzet *et al.,* 1983; Pergent *et al.,* 1983, 1989, 1995; Pergent-Martini, 1998).

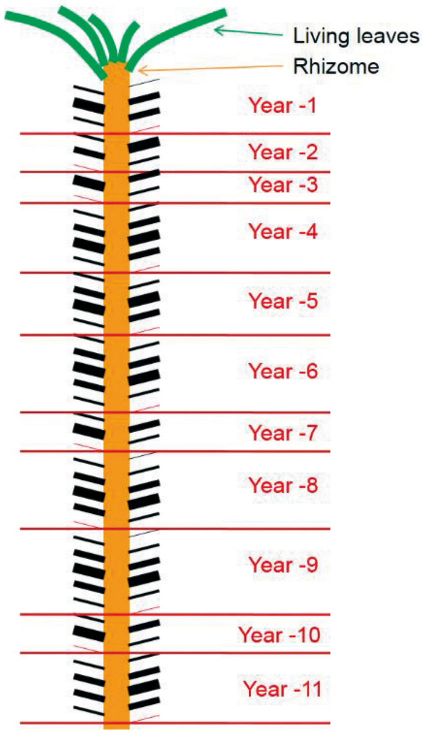

Figure 22. An orthotropic rhizome of *Posidonia oceanica*. Scales (remains of shed leaves), corresponding to past years (-1 through -11) are symbolized by a bar. The thickness of the scales varies over the year; the thinnest scale is in red and marks the change of year. The number of scales per year differs between years and characterizes a given year. Charles-François Boudouresque: original drawing.

Since then, **lepidochronology** has become a kind of 'Swiss army knife' of benthic ecology in the Mediterranean (Pergent and Pergent-Martini, 1990). It made it possible to understand the construction of the hill type, the tiered and the striped meadows (Boudouresque *et al.,* 1985, 1986a), to quantify the longevity of a *P. oceanica* rhizome (up to 44 years; Boudouresque, 1986), to measure its speed of growth (up to 7.7 cm per year; Boudouresque and Jeudy de Grissac, 1983; Boudouresque *et al.,* 1984), to assess the biomass in a *P. oceanica* meadow (including roots and rhizomes; Table I; Boudouresque and Jeudy de Grissac, 1986a), to assess the primary production of rhizomes

(28 to 42 g dry mass/m²/year; Boudouresque *et al.,* 1983b), to assess and date old levels of trace elements (Carlotti *et al.,* 1992; Pergent-Martini, 1998), and find traces (in the form of radioactive isotopes) of the nuclear tests of the 1960s and of the Chernobyl accident in 1986 (Calmet *et al.,* 1986, 1988, 1991; Carlotti *et al.,* 1992), etc.

Table I. Biomass (g dry mass/m²) of some biotic compartments in a hill type *Posidonia oceanica* meadow, L'Elbu Cove, 17 m depth, Scàndula Nature Reserve (Corsica). md = missing data. From Boudouresque and Jeudy de Grissac (1986a).

Compartment	Sample 1	Sample 2	Sample 3
Living rhizomes	911	1 771	1 956
Scales of living rhizomes	1 257	1 501	2 556
Living roots	351	743	911
Leaves	654	808	834
Leaf epiphytes (flora and fauna)	49	61	63
Epiphytic flora of rhizomes	6	md	50
Epiphytic fauna of rhizomes	3	md	11
Total biomass	**3 230**	**>4 885**	**6 380**

In 1978, a **permanent quadrat** was set up on the *P. oceanica* meadow (hill type) of L'Elbu Cove (Antona *et al.,* 1981a; Boudouresque *et al.,* 1981, 1986b, 2007). It measures 10 m x 10 m, and is located at 17 m depth. It was staked out by 8 cement markers, numbered from 1 to 8, at the corners and in the middle of the sides. The mapping of the permanent quadrat was performed both by direct observation (scuba diving), using a graduated metal frame, and by underwater photography of each one metre square, to an accuracy of 20 cm. The follow-up of this permanent quadrat yielded many lessons. It revealed the relatively rapid dynamics of the meadow: the margin progresses, recedes, the rhizomes become bare (lose their sediment), *intermattes* of dead *matte* are formed, etc. Given the slow growth rate of the rhizomes, such a dynamic was not suspected, nor such a rapid progression of the meadow. This modest permanent quadrat has become invaluable and led to a small revolution in the interpretation of changes in the boundaries of the *P. oceanica* meadow. In the absence of human impact, they can change very quickly, under the simple effect of the rhizome growth dynamics and hydrodynamics (Fig. 23; Boudouresque *et al.,* 1986b; Astruch *et al.,* 2008; Boudouresque *et al.,* 2012). Many other permanent quadrats have been subsequently set up, in the framework of *P. oceanica* meadows monitoring, on the model of that of Scàndula (e.g. Gravez *et al.,* 1993, 1997; Boudouresque *et al.,* 2000; Charbonnel *et al.,* 2003; Boudouresque *et al.,* 2007).

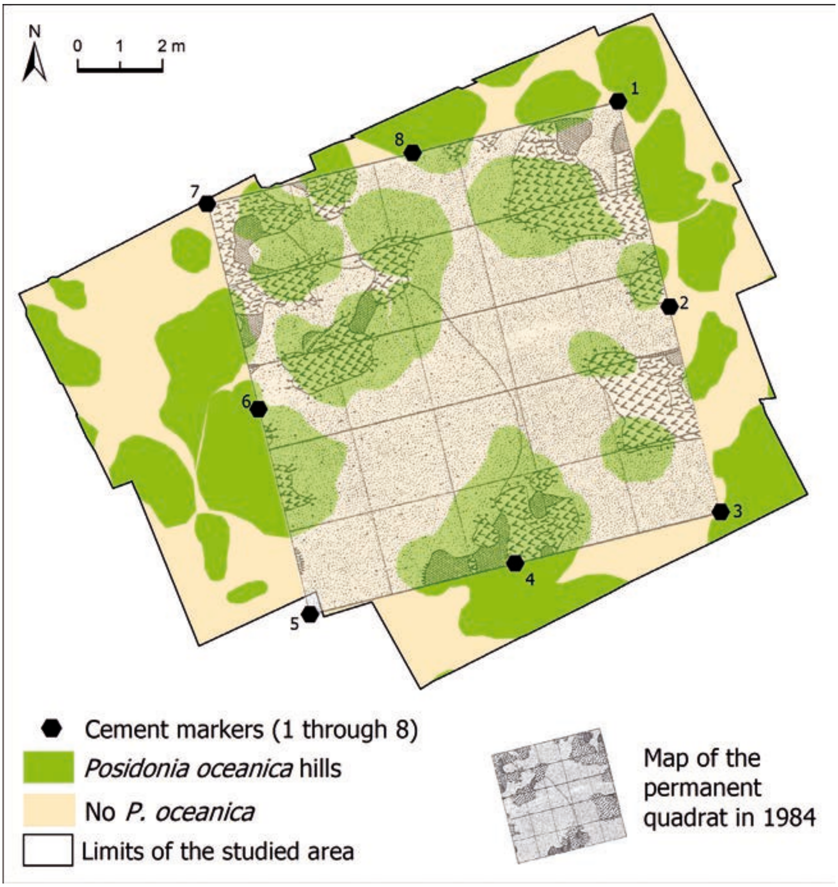

Figure 23. The permanent quadrat on the *Posidonia oceanica* meadow (hill type) of the L'Elbu Cove. It was set up in 1978. Here, the 1984 map (black and white) is superimposed on that of 2008 (in colour). The cement markers 1, 2 and 8, still in place, were used to fit the 2008 map with the 1984 map. The other markers had been displaced to a greater or lesser extent by the anchors of the pleasure boats which are numerous at L'Elbu Cove. From Astruch *et al.* (2008), adapted.

In 1977, 13 permanent cement markers were laid down at the **lower limit** of the *P. oceanica* meadow of L'Elbu Bay, 35-36 m depth, forming a ***balisage*** (Antona *et al.,* 1981a; Meinesz and Bianconi, 1986; Meinesz *et al.,* 2002). A buoy was placed above each marker, in order to make it easier to locate by divers; a 0.5 m high 'photo-stand' was placed 1.5 m ahead of each marker, facing the meadow limit. During the field survey, three photographs of the marker, a graduated scale and the surrounding meadow were taken from the top of the photo-stand (Boudouresque *et al.,* 2000, 2007). The purpose of the *balisage* was (and still is) to measure, with centimetre precision, the advance or withdrawal of the lower limit, before attempting to understand the potential causes: change in the transparency of the water linked to human activities; natural changes linked, for example, to the climatic cycles of the NAO (North Atlantic Oscillation); or change in the efficiency of photosynthesis linked to sea water warming and/or its CO_2 content? (Bonhomme *et al.,* 2010a, 2010b). The L'Elbu *balisage* was not the first in the Mediterranean: the first one was that of the Port-Cros National Park (Provence), set up in 1970 and 1972 by Harmelin (1976); a second one was put into place in 1975 in the Bay of Villefranche-sur-Mer (French Riviera) by Meinesz (1977). Subsequently, *balisages* have become a standard method all around the Mediterranean Sea (Boudouresque *et al.,* 2007; Bonhomme *et al.,* 2010a, 2010b; Pergent *et al*., 2019). As far as the 1977 L'Elbu *balisage* is concerned, the withdrawal of the limit began as early as 1979; the decline was accentuated in 1986-1989 and is now general: between 0.3 and 22 m in 2002 (Fig. 24) (Meinesz *et al.,* 2002; Lassauque and Meinesz, 2009). It is widespread in Corsica (Pergent *et al.,* 2014, 2015, 2019).

Figure 24. The withdrawal of the *Posidonia oeanica* lower limit. L'Elbu Bay. The markers forming part of the Meinesz *balisage* (Meinesz and Bianconi, 1986), once close to the meadow limit, are now far from it. April 2018. Photos © Gis Posidonie.

The map of the L'Elbu Cove benthic habitats (Meinesz *et al.,* 1988, 1998) - *P. oceanica* meadow, dead matte, reefs with photophilic algae, sand, shingles, etc. - was probably the most precise, at the scale of the Mediterranean and at the time. It included aerial photo data and the grid of the area, covered by scuba diving along graduated ropes. It is interesting to note that a mapping of the whole area, on a more regional scale, with side-scan sonar (Andromède Océanologie, 2011), produced inconsistent results for L'Elbu Cove: the *P. oceanica* areas are mapped as reefs, there is sand where Meinesz *et al* (1988) observed *P. oceanica*, and a few other discrepancies. This does not invalidate the methods used by Andromède Océanologie (2011), but highlights how much, in mapping, what is satisfactory and sufficient on a regional scale can be very different from that on a very local scale. There is no contradiction between the two scales: simply, the objectives are not the same.

In the same way, the lower limit of the *P. oceanica* meadow of L'Elbu Bay has been mapped with metric precision (Meinesz *et al.,* 1987, 1989). We must not consider that this precision, acquired using methods that we could now consider as 'artisanal' (diving, landmarks, hydrographic circle), is illusory. It had the disadvantage of being very time-consuming, but the precision is still unmatched. The lower limit lies between 33 and 39 m depth (Meinesz *et al.,* 1987, 1989, 2008). This depth may seem modest compared to greater depths that appear in the literature (e.g. Augier and Boudouresque, 1979; Marbà and Duarte, 2010). But we consider that the latter are often errors in the measurement of depth.

The fan mussel *Pinna nobilis* (up to 1 m high), endemic to the Mediterranean, is a common dweller in *P. oceanica* and *Cymodocea nodosa* meadows, together with coastal lagoons habitat. It is a filter feeder and its longevity is over 40 years (De Gaulejac and Vicente, 1990; Butler *et al.,* 1993; De Gaulejac and Vicente, 1995; Trigos *et al.,* 2014; Rouanet *et al.,* 2015; Deudero and Vázquez-Luis, 2016; Trigos *et al.,* 2018; Soufi-Kechaou *et al.,* 2019; García-March *et al.,* 2020b; Vicente, 2020; Brunet *et al.,* 2021) (Fig. 25). In the Scàndula Nature Reserve, its density was up to 20 individuals per 100 m² (Vicente and Moreteau, 1988; Vicente *et al.,* 1989, 1992; Vicente and de Gaulejac, 1994, 1995, 1996; Vicente, 2010; García-March and Vicente, 2011; Vicente and Trigos, 2013; Vicente *et al.,* 2018, 2020). The species was threatened, in most Mediterranean areas, by anchors and trawls (which broke the shells) and by poaching by divers (as a souvenir) (Vicente and Moreteau, 1991; Boudouresque, 2003; Šiletić and Peharda, 2003; Katsanevakis, 2007). It is protected by a European Union (EU) directive (Habitats Directive, 92/43, Annex IV). Another species of fan mussel, *Pinna rudis*, also protected at EU level, is present at Scàndula, but it is less common than *P. nobilis* (Fig. 25) (Vicente 2020, 2021).

Since autumn 2016, a disease that appeared in Spain has exterminated most of the populations of *P. nobilis* throughout the Mediterranean, with the exception of populations dwelling in coastal lagoons (e.g. Diana in Corsica and Thau in Occitania, Ebro Delta in Spanish Catalonia, Mar Menor in southern Spain); at Scàndula, the mortality was almost 100 % (Fig. 26) (Cabanellas-Reboredo *et al.,* 2019; Simide *et al.,* 2019; Vicente, 2019; Foulquié *et al.,* 2020; García-March et *al.,* 2020a ; Kersting *et al.,* 2020). The agent is a single-celled parasite, *Haplosporidium pinnae* (kingdom Rhizaria), hitherto unknown in the Mediterranean (Catanese *et al.,* 2018). This parasite presents all the characteristics of a recent biological transfer from an introduced host to a native new host (e.g. low genetic diversity, pattern of expansion, severe mortality of the host, etc.) (for the characteristics of a probably introduced species, see Combes, 1995; Ribera and Boudouresque, 1995; Boudouresque, 1999b; Boudouresque *et al.,* 2020c). In addition, *Haplosporidium* species are well known from China, Japan and Korea; although the proper vector species has not been still identified, shellfish aquaculture and importation of spat from Asia to Europe are suspected to be the vector (Boudouresque *et al.,* 2020b, 2020c). Potential natural recovery of *P. nobilis* from this dramatic situation relies on **(i)** larval supply and transport from unaffected sites and **(ii)** the existence of resistent individuals in the affected sites (Belloni and Astruch, 2020 ; Kersting *et al.,* 2020); SNR (Corsica) and Les Embiez Islands (Provence) are the only French sites where larval collectors have been moored to assess the presence or absence of recruitment; the presence of a few recruits in the SNR, in 2019 is encouraging news (Kersting *et al.,* 2020).

Figure 25. **Left:** adult individual of fan mussel *Pinna nobilis* at the edge of a *Posidonia oceanica* seagrass meadow, on pebbles (Gargalu, Scàndula). Note the epibionts on the shell, including the red alga *Sphaerococcus coronopifolius*. **Right**: another *Pinna* species, *P. rudis*, 26 m depth, at the entrance of a cave (Palazzu, Scàndula). Photos © Nardo Vicente.

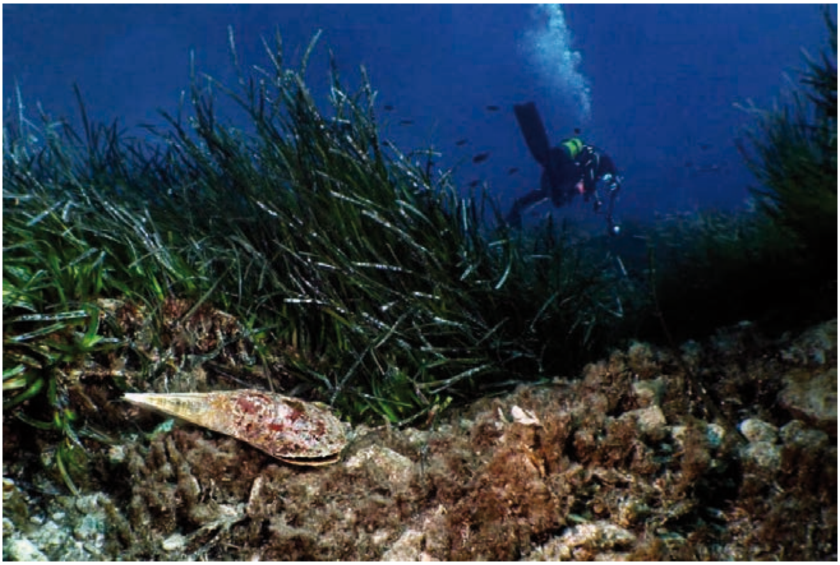

Figure 26. Dead *Pinna nobilis* at Scàndula (Gargalu pass), in October 2018. Photo © Nardo Vicente.

Two indices account for the health status of the *P. oceanica* meadow. **(i)** The **MCAI** (Multi-Critera Anchorage Index) accounts for damage due to anchoring (Rouanet *et al.,* 2012, Bonhomme *et al.,* 2013; Rouanet *et al.,* 2013). At L'Elbu Bay, the MCAI (which ranges from bad to high) is moderate to good, an unexpectedly low score for an area located in an emblematic MPA (Dossmann, 2019; Schohn *et al.*, 2019a). **(ii)** The **EBQI** (Ecosystem-Based Quality Index) accounts for the quality of the whole ecosystem and its functional compartments (Ruitton *et al.,* 2013; Personnic *et al.*, 2014; Boudouresque *et al.,* 2015b; Ruitton *et al.,* 2017). The EBQI therefore contrasts with indices based on the species itself, *P. oceanica*, or a small number of affiliate species, such as POMI (Romero *et al.,* 2007), PREI (Gobert *et al.,* 2009), and BiPo (Lopez y Royo *et al.,* 2010), which moreover are not intended to provide information on the ecosystem, but on the quality of the water. Like the MCAI, the EBQI reflects a relatively modest quality of the *P. oceanica* ecosystem at Scàndula (Personnic *et al.*, 2014; Boudouresque *et al.,* 2015b; Dossmann, 2019; Schohn *et al.*, 2019a). Overall, MCAI and EBQI show that both anchoring and fishing pressure could overcome the resilience of the ecosystem. However, if we compare the average and maximum density of anchorages per hectare at Scàndula (see section 'frequentation') with other regions of the Mediterranean (Brigand *et al.,* 2003; Frachon, 2011; Frachon *et al.,* 2013), and with the guideline values proposed by Boudouresque *et al.* (2012), it is not very high. The reason could be that, for the carrying capacity of a habitat, the guideline values are not a 'magic number', but just indicative. Each site constitutes a particular case; medical researchers call it 'idiosyncracy'; the sensitivity of a *P. oceanica* meadow depends in particular on the structure of the *matte*, the size of the sediment particles, the density of the shoots, the hydrodynamics and the type of meadow (Boudouresque *et al.,* 1995; Ganteaume *et al.,* 2005; Ceccherelli *et al.*, 2007; Boudouresque *et al.,* 2009, 2012). The type of anchors and the size of the boats also matter (Milazzo *et al.,* 2004; Abadie *et al.,* 2016; Deter *et al.,* 2017).

3.3.3. The **Lithophyllum byssoides** *algal rims: the first ecosystem disaster?*

Lithophyllum byssoides is a calcified cushion-like red alga (Rhodobionta, kingdom Archaeplastida). It thrives in rocky and relatively shady habitats, in semi-exposed and exposed conditions, just above mean sea level, in a zone characterized by the oscillation of the waves and tide, the lower mid-littoral zone (Blanc and Molinier, 1955; Molinier, 1960; Pérès and Picard, 1964; Laborel, 1987, Laborel *et al.,* 1994a). The coalescence, stacking, and durability of the individuals when dead, results in formations that are as hard as stone, are highly resistant to waves and storms and can reach a width of 2 m. They are known as *L. byssoides* algal rims or *trottoirs* (Pérès and Picard, 1964; Laborel, 1987; Boudouresque, 2004; Blanfuné *et al.,* 2016b). The Scàndula nature reserve harbours the widest and most spectacular Mediterranean *L. byssoides* rim (Fig. 27) (Bianconi *et al.,* 1987; Boudouresque *et al.,* 1992a; Blanfuné *et al.,* 2015, 2016b).

Figure 27. The Cala Litizia (Punta Palazzu, Scàndula nature reserve) *Lithophyllum byssoides* algal rim in 1983. Up to 2 m width. Photo © J.G. Harmelin (courtesy of the author).

The *Lithophyllum byssoides* algal rim has been fully mapped twice, in 1981-1986 (Bianconi *et al.,* 1987) and in 1993-1996 (Meinesz *et al.,* 1999), along the 39 km of coastline of the reserve (at the scale considered), along stretches of 50 m and 20 m, respectively. The baseline thus available is unique in the Mediterranean.

Although it belongs to the marine realm, the *L. byssoides* algal rim ecosystem forms a frontier between the marine and terrestrial realms. It harbours both typically marine taxa, such as the encrusting coralline *Neogoniolithon brassica-florida*, and typically terrestrial taxa such as the arachnid *Mizaga racovitzai* (Pérès and Picard, 1964). Two species of mosquitos, the larvae of which thrive in the small pools of the upper surface of the *trottoirs*, have been described from Scàndula: *Clunio boudouresquei* and *Thalassosmittia ballestai* (Moubayed-Breil and Dominici, 2019).

The bioconstruction of *L. byssoides* algal rims is only possible during periods of stable or slightly rising sea level (Faivre *et al.,* 2013; Blanfuné *et al.,* 2016b). After the Last Glacial Maximum (LGM), 20 000 years ago, when the sea level was 120-130 m below the current level (Lambeck and Bard, 2000), the sea level rose steadily; the speed was up to 3.7 m/century (Collina-Girard, 2003, 2012) then slowed down in the last millennia. In Corsica, the sea level was 3.8 and 0.9 m below the current level, 5 500 and 2 500 years ago, respectively (Vacchi *et al.,* 2017). The formation of a *L. byssoides* rim corresponds to cold episodes, when the polar ice sheets stop melting and Alpine glaciers advance, more or less stabilizing the sea level; the current rim corresponds to the LIA (Little Ice Age; 13th through 19th centuries CE) (Fig. 28). Former rims, which today are submerged and increasingly bioeroded by sea urchins (*Paracentrotus lividus*), date mussels (*Lithophaga lithophaga*), boring sponges (such as *Cliona* sp.) and Cyanobacteria, were constructed during the DACP (Dark Age Cold Period; ca. 2nd through 8th centuries CE) and in earlier cold periods (Fig. 28) (Blanfuné *et al.,* 2016b).

By the end of the LIA (mid-19th century), the sea level had resumed its rise. This rise was at first slow (0.4 mm/a) ([2]) but, due to the human-induced amplification of climate warming, resulting in the melting of polar ice sheets and of mountain glaciers together with the thermal expansion of the seawater, the sea-level rise steadily accelerated. It has reached 3.4 mm/a (Nicholls and Cazenave, 2010) and even, today, 3.5-4.0 mm/a (Chao *et al.,* 2008; Meola and Webster, 2019); it could reach 40 mm/a by 2100. By the end of the 21st century, the rise will probably be within the range 26-82 cm (Lootvoet *et al.,* 2016), but a much greater rise in sea level cannot be ruled out (DeConto and Pollard, 2016; Blanfuné and Boudouresque, 2018). In any case, this rise will continue

[2] The symbol for 'year' in the international system of units (SI, Système International) is 'a' (from Latin annum).

since, at the end of three out of the last four interglacial periods, the final sea level was probably several meters above the current sea level (Waelbroeck *et al.,* 2002).

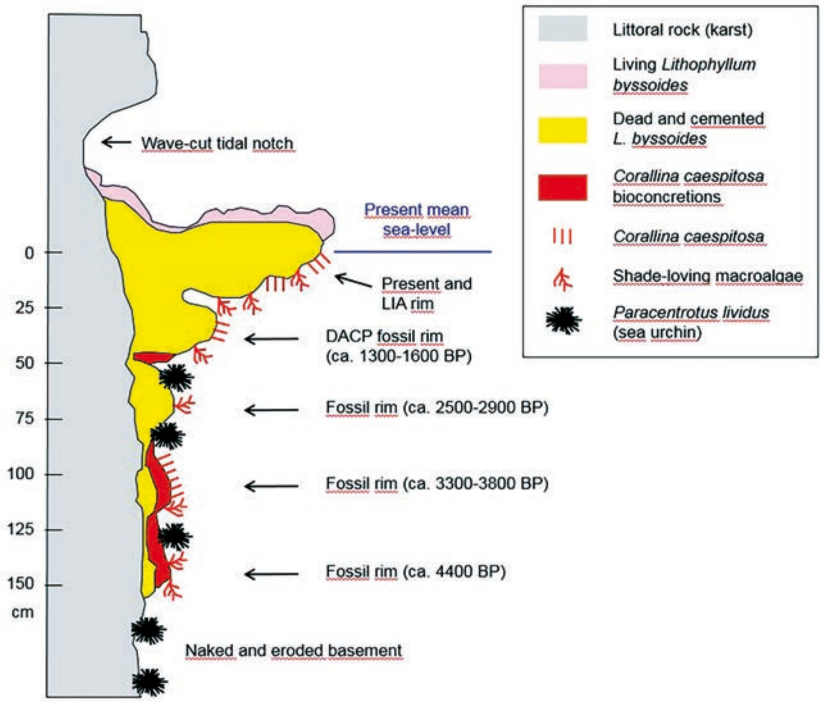

Figure 28. Profile of a cliff near Marseille (Provence, France) showing the structure of the present *Lithophyllum byssoides* rim (LIA and post-LIA) and the remains of the previous submersed rims that are gradually disappearing under the influence of sublittoral bioerosion. A similar profile was observed at Scàndula. From Laborel and Laborel-Deguen (1996), redrawn and simplified by Blanfuné *et al.* (2016b).

The reconstruction of the rise in sea level in the Mediterranean Sea, over the past 5 000 years, by Laborel *et al.* (1993b), Laborel (1994) and Collina-Girard (2003, 2012) was based on data from La Ciotat, near Marseille (western Provence), Port-Cros Island (eastern Provence) and Punta Palazzu (Scàndula, Corsica) (Laborel *et al.,* 1983; Boudouresque *et al.,* 1992a; Laborel *et al.,* 1994b).

For the *L. byssoides* algal rims, a slow growing bioconstruction, the current rise in sea level is too fast. As a result, *L. byssoides* rims have begun to be submersed throughout the Mediterranean. While they formerly belonged to the lower mid-littoral zone, they have progressively 'shifted' to the infralittoral zone (*sensu* Pérès and Picard, 1964) (in fact, it is the infralittoral zone that has 'shifted' upwards). The ecosystem engineer species *L. byssoides* then dies and is covered by infralittoral species such as soft red algae and articulated corallines (e.g. *Corallina caespitosa*). Subsequently, the dead, 'subfossil' algal rim is bioeroded by endolithic photosynthetic and heterotrophic borers, and by grazers. The rim is perforated by holes of increasing size (Fig. 29) and its width and thickness decrease. The total destruction of a subfossil rim may require five millennia (Blanfuné *et al.,* 2016b, 2016c). Under exposed conditions, the *L. byssoides* rim protrudes higher than under semi-exposed conditions; consequently, rims that thrive under semi-exposed conditions are more sensitive to the ongoing rise in sea level (Blanfuné *et al.,* 2016b).

The media and scientists often draw the attention of the public to the flooding of Pacific atolls and the States that are affected as a result. It is worth drawing attention to the fate of the Mediterranean *L. byssoides* algal rims, an ecosystem endemic to the Mediterranean Sea, and to its forecast collapse; it would be worldwide the first case of marine ecosystem collapse resulting, indirectly, from global warming and man-induced global change (Thibaut *et al.,* 2013; Blanfuné *et al.,* 2016b, 2016c). As in other parts of the Mediterranean, the *L. byssoides* rims in Scàndula are in a poor state, due to both their submersion and trampling (Verlaque *et al.,* 2010; Aurélie Blanfuné, unpublished data).

Figure 29. A dead, highly eroded, *Lithophyllum byssoides* rim, in 2014, at Punta Palazzu, Scàndula, Corsica. Photo © Thierry Thibaut (courtesy of the author).

In addition to the rise in sea level, *L. byssoides* rims are threatened by pollution, by trampling and by the friction of boats and their mooring ropes, when these boats try to unload tourists on the *trottoir* (Laborel *et al.,* 1994a; Verlaque, 2010; Blanfuné *et al.,* 2015). Note that the iconic algal rim at Cala Litizia (Punta Palazzu, Scàndula) (Fig. 27) appears in recent tourist guides and has featured in the tour programme of several tour operators ('Corsica tour in inflatable boat').

***3.3.4. The giant limpet* Patella ferruginea**

The giant limpet *Patella ferruginea* is a Mediterranean endemic (Laborel-Deguen and Laborel, 1991; Espinosa and Ozawa, 2006). Its size (up to 11 cm in diameter) is unusual for a limpet, which makes it the largest limpet species in the world. It lives in the midlittoral zone, slightly above mean sea level, on rocky substrate under exposed conditions. It was formerly widespread throughout the western Mediterranean (Laborel-Deguen, 1985; Laborel-Deguen and Laborel, 1991; Boudouresque, 2004). The giant limpet has been harvested by humans either for consumption or as bait. Human consumption is ancient: shells are not uncommon near Neolithic human habitats throughout the western Mediterranean, e.g. in a cave on the Tuscan island of Pianosa (Italy), north-east of Corsica (Imperatori, 1968; Carnieri and Zamagni, 2000; Colonese *et al.,* 2011). The giant limpet is still actively collected by man; in areas where it survives, its presence and abundance are inversely proportional to the accessibility of sites and their frequentation by humans: Tunisia (Tlig-Zouari *et al.,* 2010), Ceuta (Rivera-Ingraham *et al.,* 2011), Corsica (Dorado, 2005) and the marine protected (or more exactly theoretically protected area) of Penisola del Sinis-Isola de Mal di Ventre (Coppa *et al.,* 2011). It now only survives in sparse populations in Corsica, Sardinia, Tunisia, Algeria and southern Spain (Laborel-Deguen and Laborel, 1991; Boudouresque, 2004). In Corsica, the giant limpet has been extirpated from roughly half of its former range; about 15 000 individuals are still present; its highest abundance occurs in the Scàndula nature reserve and near Ajacciu (Antona *et al.,* 1981a; Laborel-Deguen and Laborel, 1991; Boudouresque *et al.*, 1992a; Dorado, 2005; Meinesz, 2020c).

The behaviour and growth of *P. ferruginea* has been studied at Scàndula and the Lavezzi Islands (Corsica) by Meinesz and Dominici (2015) and Meinesz (2020c), by marking individuals with coloured beads on a sticky paste. A 6 cm individual is 6 years old; longevity can reach 19 years; most individuals do not move beyond 1 m from their home, although they can move up to 10 m (Meinesz and Dominici, 2015; Meinesz, 2020c).

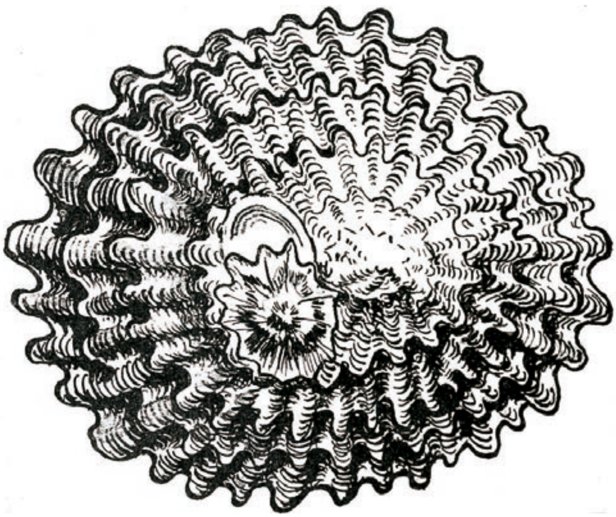

Figure 30. The giant limpet *Patella ferruginea*. A large specimen sighted at Scàndula (Corsica). A juvenile is attached to the shell of an adult (a little to the left of the center of the shell). Drawing by Pierre Bonnard, for a leaflet by Laborel F. *et al.* (1985) (courtesy of Françoise Laborel).

There are many reasons for the decline of *Patella ferruginea* (Laborel-Deguen and Laborel, 1991). **(i)** Its size makes it very visible and the first to attract the attention of limpet gatherers. **(ii)** Its longevity (Dorado, 2005), which is often a risk factor. **(iii)** Its habitat (the midlittoral zone) makes it accessible to snorkelers, anglers and wandering walkers. **(iv)** The change of sex with age (the young individuals are males, the oldest and therefore the largest are females) hampers the production of eggs in an exploited population: the individuals harvested tend to be the largest and therefore the females. **(v)** The fact that juveniles take refuge on the shell of adults (Fig. 30) was considered by Laborel-Deguen (1985) and Laborel-Deguen and Laborel (1991) a risk factor: those who harvest *P. ferruginea* collect the recruits at the same time. In fact, this is not a general behaviour pattern, nor specific to *P. ferruginea* (Casu *et al.,* 2006; Meinesz, 2020c). In contrast, pollution does not seem to negatively affect the giant limpet (Doneddu and Manunza, 1992; Guerra-Garcia *et al.,* 2004, Espinosa *et al.,* 2009), although it was initially blamed by Laborel-Deguen and Laborel (1991).

From 1983 to 1992, a worrying decline in the density of *P. ferruginea* was observed in the SNR (Laborel-Deguen *et al.,* 1993), despite the efficiency of its management and the strictness of the surveillance by the wardens (Table II). According to Boudouresque *et al.* (2005), a possible reason for this unexpected decline was that the prevailing current, running south to north, which comes from regions devoid of giant limpets, does not bring larvae into the reserve; the larvae produced by the individuals harboured within the reserve are swept away outside the reserve by the current. The conclusion of Boudouresque *et al.* (2005) was that the protection of the habitat may prove to be inefficient, if the size of the protected area is too small (which is the case of the SNR), and significant numbers of planktonic larvae are dispersed by currents. But density increased slightly in Scàndula in 1993-1995 and it increased 7-fold in the Lavezzu reserve (Bunifaziu Straits) between 1992 and 2012 (Meinesz, 2013), which suggests that there must be some self-recruitment.

Table II. The decline in abundance of the giant limpet *Patella ferruginea* at two sites of the Scàndula Nature Reserve (Corsica). Data from Laborel-Deguen *et al.* (1993) *in* Boudouresque *et al.* (2005). md = missing data.

Year	Mean number of individuals per 100 m of shoreline	
	North face of Capu Gargalu	Cala Litizia (Punta Palazzu)
1983	md	25
1984	56	19
1987	md	21
1992	24	2

3.3.5. The precious red coral **Corallium rubrum**

Former populations of the precious red coral *Corallium rubrum* have been almost extirpated throughout the Mediterranean Sea because of historical over-exploitation (Cattaneo-Vietti *et al.,* 2016). Between 1980 and 1985, an exhaustive panorama of precious red coral *Corallium rubrum* populations, in the SNR and in its vicinity (gulfs of Galeria and Ghjirulatu), was drawn up by Bianconi *et al.* (1988). It is an exceptional work, based on 71 dives, some beyond 50 m depth; it provided a unique baseline in the Mediterranean for this emblematic and overexploited species (Boudouresque *et al.,* 1992a). A cave between 20-30 m depth in the no-take zone of Scàndula represented one of the most abundant red coral populations (number of colonies/m², diameter of trunks - i.e. age) in shallow waters known in the Mediterranean (together with a population in the Côte Bleue Marine Park; J.G. Harmelin, pers. comm.). Shallow waters had been exploited since antiquity using the highly destructive St. Andrew's Cross: a metal bar or a cross with nets hanging from it, dragging on the bottom, towed by a boat. The only large red coral colonies left in shallow waters were those in caves the cross could not reach, but with the advent of scuba diving, the red coral in those shallow caves was wiped out in only a few decades (Cattaneo-Vietti *et al.,* 2016). Therefore, the cave in the no-take zone of Scàndula was thought to be the shallow water population of red coral closest to the baselines in the Mediterranean. Yet, in 2010, during the course of a grouper survey, J.G. Harmelin accidentally discovered an exceptional population of *C. rubrum* in a previously unexplored shallow underwater cave ('Cave b'), between 18 and 27 m depth, also in the no-take zone of the SNR (Garrabou *et al.*, 2017) (Fig. 31). The abundance and biomass of large colonies (>10 cm in height or 7 mm in basal diameter) in the Cave b population are 1 to 3 orders of magnitude greater than those in other populations harbouring large colonies; and their biomass in Cave b is 7.5 times higher than at the other cave in the no-take zone of Scàndula. This discovery showed that the baseline for 'natural' red coral populations in the Mediterranean was even more biased than we thought because of the scarcity of dense shallow populations. This finding showed again the extraordinary value of the Scàndula reserve as a baseline for Mediterranean marine ecosystems.

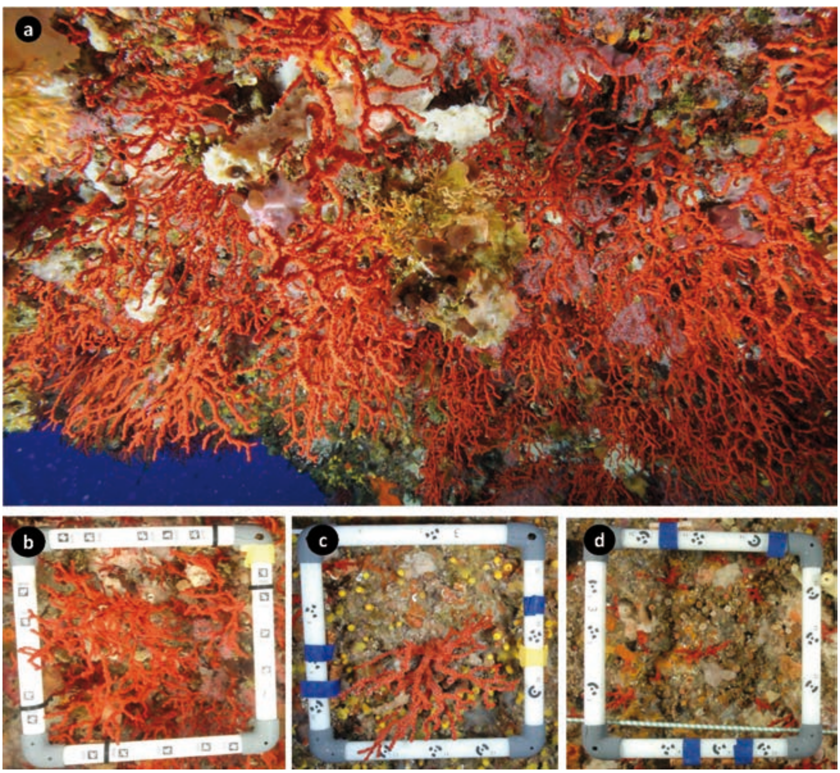

Figure 31. The extraordinary red coral population between 18 and 27 m at 'Cave b' in the Scàndula Nature Reserve (a, b), compared with another shallow cave in Scàndula (c), and a standard population from an unprotected area (Provence, France) (d). From Garrabou *et al.* (2017).

3.3.6. Other marine invertebrates

The abundance of the actinian *Actinia mediterranea* (as *A. equina*)[3] was fully mapped in 1993-1996 (Meinesz *et al.,* 1999) along the 39 km of coastline of the reserve (at the scale considered), along 20 m stretches. The baseline thus available is unique in the Mediterranean. The bryozan *Hornera frondiculata*, endemic to the Mediterranean, is present at Scàndula (Palazzu Islet, 35 m depth) (Harmelin, 2020).

Eight species of sea slugs (molluscans) have been observed (Vicente, 1987); the most common is the doridian *Peltodoris atromaculata;* tectibranchs are also present such as *Notarchus punctatus* in the Bay of Galeria living on *Posidonia oceanica*. The other nudibranchs live mainly in the coralligenous like the species found mainly on the hydraria they feed on; in particular, the aolidians *Flabellina affinis* and *Cratena peregrina;* we also observed *Facelina gabinieri,* described in Port-Cros National Park (Vicente, 1975). Merella *et al.* (1992) listed 265 species of molluscs; some of them are rare in the Mediterranean, so that their sighting at Scàndula deserves to be highlighted: *Ammonicera fischeriana, A. rota, Cuspidaria rostrata, Cymatium parthenopaeus, Erato voluta, Heliacus falaciosus, Irus irus, Lepidopleurus algeriensis, Muricopsis diadema, Parvicardium transversale, Patella ferruginea, Philine scabra, Scissurella crispata, Skeneopsis pellucida, S. planorbis* and *S. sultanarum*. The deep-sea gastropod *Pseudosimnia carnea* has been observed at 30 m depth, on *Corallium rubrum* (Francour *et al.,* 1992).

Larval harnessing, carried out from 1996 to the present day, to look for recruits of *Pinna nobilis,* has produced numerous larvae from various zoological groups, in particular molluscs and crustaceans. For molluscs, the most common species were: *Musculus subpictus, Lima hians, Hiatella rugosa, Chlamys varia, Flexopecten flexuosus, Anomia ephippium,* and *Rissoa ventricosa.* For crustaceans, *Galathea strigosa, Eriphia spinifrons, Caprella linearis* and *Penaeus* sp. were the most commonly recorded (Vicente *et al.*, 2020)

This regular larval harnessing at various stations of the SNR makes it possible to follow the patterns of change in the biodiversity over time.

Boudouresque *et al.* (1989) listed 31 species of echinoderms; a further species, the very rare and tiny *Arbaciella elegans*, has been sighted in the Gulf of Galeria (Merella *et al.,* 1994). The rare diadema

[3] Molecular studies have shown that the Mediterranean population belongs to a species that is distinct from the Atlantic species, *Actinia equina*. The Mediterranean species is now named *A. mediterranea* (Monteiro *et al.,* 1997).

sea urchin *Centrostephanus longispinus* is not uncommon (Verlaque *et al.,* 1999b). Four species of bryozoans of the genus *Collarina* are present at SNR: *C. balzaci, C. denticulata, C. gautieri* and a still undescribed species (Harmelin *et al.,* 2019).

Unfortunately, a number of taxa have not been specifically studied at the SNR, e.g. sponges, cnidaria (with the exception of *Corallium rubrum*) and bryozoans (with the exception of the genus *Collarina*).

3.3.7. Marine turtles and mammals (other than the monk seal)

Only one species of sea turtle has been observed in the SNR, the loggerhead *Caretta caretta*; it is sometimes caught in fishing nets (Boudouresque and Jeudy de Grissac, 1986b; Delaugerre, 1986). Loggerhead turtles may have nested on sandy beaches throughout Corsica in the past (Delaugerre, 1987), but recently only one very rare nesting event was detected at Palombaggia beach south of Portivechju, southeastern Corsica (Delaugerre and Cesarini, 2004).

The bottlenose dolphin *Tursiops truncatus* is commonly encountered in Scàndula waters all year round, except during high tourist season (Anonymous, 2007). Dolphins, especially *T. truncatus*, are blamed by fishermen for consuming fish caught in nets and making holes in the nets. A study of the interactions between Corsican fishermen and *T. truncatus* showed that: **(i)** 11 % of fishing nets were attacked and often damaged; **(ii)** there was a significant increase in CPUE (catch per unit effort) when there were direct attacks or when dolphins were simply present in the area; explanations for this phenomenon were that either dolphins actively drive fish into the fishing nets with a view to consuming them after doing so, or that the fishermen and dolphins both go to the areas where there are the most fish and where fishing proves more productive (Maggiani *et al.,* 2002; Anonymous, 2007; Mahouche, 2007).

It may occasionally happen that a Mediterranean whale (*Balaenoptera physalus)* or a sperm whale (*Physeter macrocephalus)* is observed in the entrance of the gulfs of Ghjirulatu and Galeria, that lie near their respective canyons (management team of the SNR pers. comm.).

3.3.8. Marine zonation

The zonation of marine stages and ecosystems in the Scàndula Nature Reserve is classical for the Mediterranean Sea (see e.g. Molinier, 1960; Pérès and Picard, 1964; Antona *et al.,* 1981a). What is unique about Scàndula is that it is probably the region of the western Mediterranean which is the freest from any human impact during most of the year: no pollution, no harbour, no coastal urbanization, no discharge of sewage (with the exception of over-frequentation by tourist boats during the late spring and summer months). If you had dived two millennia ago at Punta Palazzu, you might have seen the same fish, the same forests of *Cystoseira*, the same meadows of *Posidonia oceanica,* the same coralligenous outcrops (see e.g. Verlaque, 2013). The main difference, and it matters, is that you would also have seen the ballet of monk seals coming to observe you with friendliness and curiosity. Of course, things are changing (the mooring of pleasure boats, the loudspeakers of sightseeing boats, etc.), but this is a question which will be developed further below (Boudouresque *et al.,* 1992a)

3.4. The extirpation of the monk seal *Monachus monachus*

The Mediterranean monk seal *Monachus monachus* (‘*u vecchju marinu*’ in Corsican) has been present throughout the Mediterranean and in the near Atlantic, from Portugal to Cap Blanc (Mauritania) for millions of years (Marchessaux, 1989a, 1989b; Lavigne, 1998). Near Marseille, it was represented by humans on the walls of the Cosquer Cave, 18 000-19 000 years ago (Clottes and Courtin, 1994). In antiquity, Homer has it intervene on several occasions, in the *Odyssey* (King, 1956; Marchessaux and Duguy, 1977). The monk seal was undoubtedly hunted in Corsica by mesolithic humans, ~7 000-8 000 BCE (Pasquet and Demouche, 2012; Vigne and De Lanfranchi, 2012). In a cave on the western coast of Corsica, remains of monk seals embedded within a fossil *banquette* of dead *Posidonia oceanica* leaves were dated (^{14}C) from the 16th and 17th century (Salotti and Pereira, 2009).

Until the 19th century, the monk seal was not uncommon in western Corsica: L’Isula, Calvi, Scàndula, Carghjese, Pruprià, etc. It frequented in particular the large sea caves of the A Rivellata and Scàndula peninsulas (Troitzky, 1953; Marchessaux, 1989a; Salotti, 2004). According to Don Dero (*in* Ruggieri, 1981), between Galeria and Ghjirulatu, in the 1930s, a hundred individuals thrived, and he could observe every morning about twenty individuals resting on the beach at Galeria (Fig. 32). By the 1950s, seal numbers had already severely declined; they were concentrated in the caves of the Scàndula Peninsula (Antona *et al.,* 1981a; Ruggieri, 1981; Weiss, 2007c). As incredible as it may seem, Prince Rainier III of Monaco killed, in a marine cave at Gargalu (Scàndula), one of the last seals in Corsica. He was taking part in a hunting trip by boat; he relates that on September 27, 1947, at the bottom of a narrow cave, he saw a seal sleeping on a red sand beach; the seal ‘*straightened up suddenly and made a threatening movement to defend himself (...). The beast had to be shot down with* *two rifle bullets*'[4] (Fig. 33) (Troitzky, 1953). This account is absurd: the monk seal is a very peaceful animal and there are no examples of wild monk seals ever attacking humans (Ballesteros, 2012). In fact, artisanal fishers deliberately shot the last Corsican monk seals at Scàndula, in 1968 or 1969 (Antona *et al.,* 1981a; Ruggieri, 1981; Thibaut and Delaugerre, 1992; Weiss, 2007c; Allegrini-Simonetti *et al.,* 2008), 1970 (Meinesz, 2020b), 1974 (Salotti and Pereira, 2009) or 1976 (Marchessaux, 1989a). The extermination of the seal in Scandula was methodical and the means used often barbaric: they were massacred with axes, pitchforks, sticks, and of course bullets, all the more easily since they are peaceful animals and show little fear (Allegrini-Simonetti *et al.,* 2008). Man has always needed to find scapegoats, in society as well as in nature. For fishermen, the blame for falling stocks and torn fishing nets was of course a predator, not their own mismanagement. The monk seal, which is a fish eater, like the dolphins, made an ideal scapegoat. In addition, according to Ruggieri (1981) and Richez and Richez-Battesti (1992), the Department of Maritime Affairs offered a bonus to fishermen for the destruction of seals. However, for over a century, all scientific studies around the world have shown that killing predators does not increase available prey, but reduces them (e.g. Gerber *et al.,* 2009). The establishment of a Marine Protected Area (MPA), at Scàndula as elsewhere in the world, and the resulting reserve effect, was of course the most cost-effective solution (Boudouresque *et al.,* 2005; Le Diréach *et al.,* 2018). But for the monk seal, it was too late.

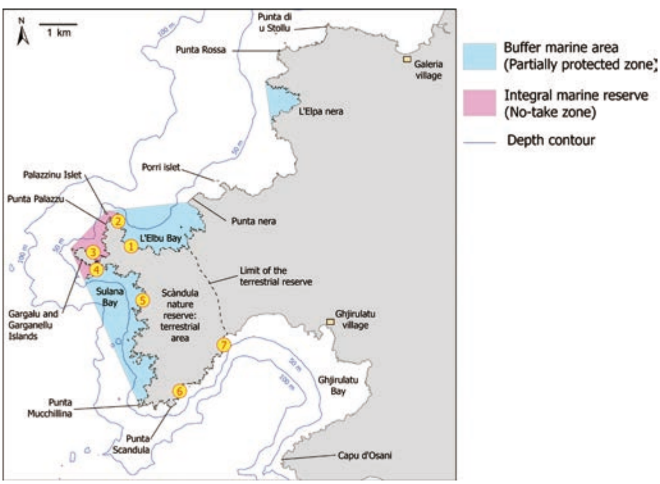

Figure 32. Location of the sea caves housing monk seals in the 1930s, in descending order of importance. 1. Puntone (L'Elbu), the main cave. 4 (Gargalu Pass) and 7 (U Figu, Cala Muretta), important. Caves 1, 4 and 7 do not have an entrance above the water surface and are only accessible by diving. 5 (Ponte) and 2 (Palazzu). Finally, 3 (Gargalu) and 6 (Scàndula), of lesser importance. Original drawing (Thomas Schohn), from data of Ruggieri (1981).

[4] Translated from French by the authors.

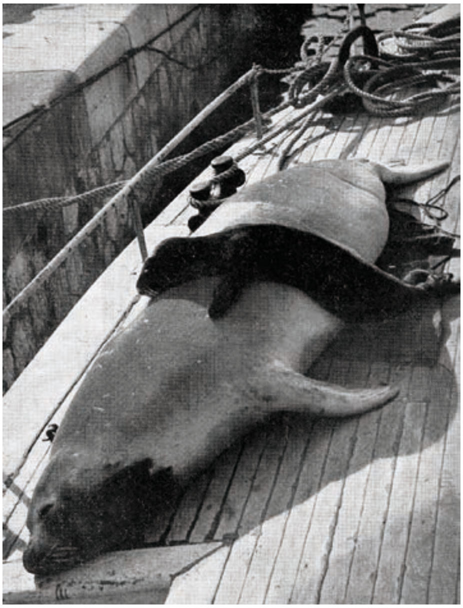

Figure 33. The monk seal killed in Scàndula during a hunting party (Troitzky, 1953) was a pregnant female. After hoisting the corpse onto the deck of the boat, it was cut open and the baby seal extracted. The mother and her calf were stuffed and exhibited for many years at the Musée Océanographique de Monaco (Weiss, 2007c). Photo © F. Picédi *in* Troitzky (1953).

It is difficult to determine the reality (or not) of competition with seals and the damage to nets and traps attributed to the monk seal. Everywhere in the world (or almost everywhere), on land as at sea, man has often justified his murderous madness towards animals under various often fallacious pretexts, the absurdity of which was easy to demonstrate. The testimonies of fishermen concerning damage to fishing nets, reported by several authors (Antona *et al.,* 1981a; Ruggieri, 1981; Felici, 1982; Weiss, 2007c), are worth what human testimonies are often worth: as the saying goes, give a dog a bad name to hang it by. A critical analysis of these testimonies remains to be undertaken. Was the monk seal such a voracious fish-eater and ripper of fishing nets? As a former fisherman recognized (*in* Ruggieri, 1981), the pleasure of hunting, like the pleasure of killing, may also have played a role in the extermination of monk seals. In Turkey, a scientific analysis of the tearing of nets attributed by fishermen to monk seals revealed that, in at least 80 % of cases, they were attributable to dolphins and especially to the snagging of nets on rocks (Õztürk and Dede, 1995); but it is so much more glorious, for the pride of a fisherman, to accuse the seals rather than one's own clumsiness. Obviously, overfishing of the fish stocks on which the monk seal feeds could lead individual seals to steal fish from fisher's nets (Boudouresque and Lefèvre, 1988, 1992; Boudouresque, 2003, 2004). For our part, we believe that the damage attributed to the monk seal, perhaps real, was negligible and was deliberately exaggerated by witnesses to justify their murderous madness.

It is interesting to note that, in Provence, at the end of the 19th century, Gourret (1894) discussed the issue of the **species harmful to fishermen**. It was the dolphins which were targeted: they *'swallow up the enamelled fish and then tear the nets to pieces, thus causing often very significant damage (...). The presence of these animals is therefore a real scourge*'[5]. Octopus, porpoise and shark were also mentioned as pests, but, it should be stressed, not the monk seal, although common at the time (Gourret, 1894; Raveret-Wattel, 1909). Many methods, some very barbaric, were used to destroy dolphins; the French navy was even called in to shoot the dolphins with a cannon! (Gourret, 1894; Raveret-Wattel, 1909; Faget, 2009). Steel needles, held in place by a biodegradable thread, were hidden in bait (ball of animal fat or fish); in the stomach of the dolphin or porpoise who had consumed them, the threads dissolved, the needles relaxed, pierced its body and caused its death in suffering that the authors of the time describe, with sadistic pleasure, as terrible (Gourret, 1894; Raveret-Wattel, 1909). In his authoritative work on fishing in Corsica, De Caraffa (1929) spoke of the worrying depletion of fish stocks; the main causes were thought to be trawls, *'which ravage the seabed and nurseries*' and fishing with explosives; nowhere does he mention the competition of seals, dolphins - nor of course ospreys -, targeted at the time like all raptors.

Is the monk seal on its way back to Corsica, from its refuges in Madeira Island – Portugal – and the eastern Mediterranean – Greece and Turkey? – (Güçlüsoy *et al.,* 2004; Nataf, 2010; Ballesteros, 2012; Meinesz, 2020b). In October 1980, a monk seal was definitely spotted on a beach, south of U Portu (Anonymous, 1982). An adult individual was sighted by one of the authors (JMD), on the evening of May 14th, 2011, between Gargalu and Garganellu Islands, Scàndula. Several other sightings, reported in 2007 by Salotti and Pereira (2009) and by Jean-Michel Culioli, from 2009 to 2015, in western, northern and southern Corsica, have been cited (see e.g. Meinesz, 2020b).

3.5. The osprey *Pandion haliaetus*: a recovery in jeopardy

The osprey *Pandion haliaetus* has a worldwide distribution, with abundant populations in North America and northern Europe, where it nests at the top of trees, near lakes and rivers, and feeds on fish which it catches in the sub-surface (Monti *et al.,* 2017; Poole, 2019). In contrast, in the Mediterranean, it mainly nests on cliffs overhanging the sea. Recent genetic studies revealed that the Mediterranean population was genetically different from other European populations (Monti *et al.,* 2015, 2018b). In addition to genetic differences, birds of the Mediterranean population tend to forage at sea and exhibit

[5] Translated from French by the authors.

limited patterns of migration, generally staying in Corsica or within the Mediterranean basin in winter, in contrast to the long-distance migration undertaken by birds from Northern Europe (Monti *et al.,* 2018c, 2018d).

The osprey has become extinct or very rare in most regions of the Mediterranean. It ceased to nest in mainland Italy in 1930, in Tunisia in 1943, in Greece and Turkey in 1966, in Sicily and Sardinia in 1968, in Andalousia in 1981 and in Portugal in 1997; and very few pairs have survived in Corsica (see below), Balearic Islands (15 pairs) and Algeria-Morocco (less than 30 pairs) (Monti, 2012; Monti *et al.,* 2017).

From the early 20th century to 1974, the number of territorial pairs of osprey in Corsica dropped from 40-100 to 3-4, only two in the area of the future Scàndula Nature Reserve (Thibaut and Patrimonio, 1990; Siblet, 2019; Dominici, 2020). Several causes have been suggested, including deliberate shooting by hunters and probably fishermen as well (Thibault, 1983; Thibaut and Patrimonio, 1990; Dominici, 2020). Raptors, including the golden eagle *Aquila chrysaetos,* peregrine falcon *Falco peregrinus* and osprey had long been classified as pests, and their destruction was encouraged by the authorities until the 1960s, in France (D'Harmonville, 1898). The osprey was considered as extinct from Corsica when Michel and Jean-François Terrasse rediscovered the last breeding pairs during a field mission in 1975. From 1977, thanks to protective measures, the setting up of artificial nests and increased public awareness, the number of ospreys has subsequently increased: 8 breeding pairs in the early 1980s, 14 in 1989, 25 in the 2000s, 32 in 2010, extending from Capicorsu (north) to Ajacciu (south) (Figs. 34, 35) (Thibaut and Patrimonio, 1990; Siblet, 2019; Dominici, 2020). At the same time, the annual number of fledgings has increased up to 35 in 1999 (Dominici, 2000). Yet the number of breeding pairs in the SNR stabilized at 8-9 pairs, probably reflecting the carrying capacity for the species on that area, limited not only by food resources or nesting sites, but also by intra-specific competition (Bretagnolle *et al.*, 2008).

The osprey's diet has been studied at Scàndula, on the basis of the remains of fish found in the nests; it is mainly made up of Mugilidae (63 %; 26 to 34 cm of total length) and *Sarpa salpa* (16 %), fish without value for the local artisanal fishery (Francour and Thibault, 1995), which excludes any competition with fishermen.

Thanks to the recovery of the Corsican population of osprey, the translocation of chicks from Corsica to Tuscany (Parc Naturel Régional de Corse and Parco Regionale della Maremma, 2006), where the species was historically present before becoming extinct, has been a success: the osprey is now present again in Tuscany, where it successfully reproduces (Monti *et al.,* 2014), with 5 active nests in 2020.

Figure 34. The banding of a fledging chick of the osprey (*Pandion haliaetus*) at Scàndula (Corsica). Left to right: Felix Santarelli and Jean-Marie Dominici, curator of the Scàndula Nature Reserve. Photo © Jean-Marie Dominici.

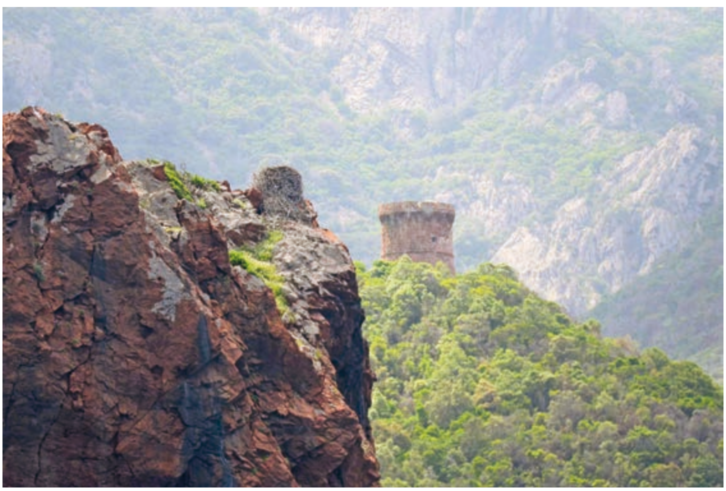

Figure 35. The osprey *Pandion haliaetus* nest at L'Elbu. In the background, the Genoese tower of L'Elbu. Photo © Jean-Philippe Siblet (courtesy of the author).

Yet the future of the osprey in Corsica has in the last decade not seemed so bright. GPS-tracking revealed that juvenile survival was low, and at least three juvenile osprey were shot by hunters in Malta, Spain and Sardinia in 2012-2013. Furthermore, the breeding parameters have progressively declined for pairs nesting in the SNR area, compared to those in the rest of Corsica, outside the SNR (Fig. 36). Although the number of pairs having laid eggs with successful hatching remains stable at Corsican scale, the number of chicks fledged has dramatically fallen (between 6 and 20 chicks per year since 2012, with a majority outside the SNR, and only 0-1 per year in the SNR) (Monti *et al.*, 2018a).

The causes of this decline could be due to habitat alteration, such as depletion of food resources, or human disturbance. A study of the distribution of the food resource (abundance of surface fishes), along 98 transects carried out in kayaks with underwater video recording, showed that the biomass and size of the fishes were higher in the SNR compared to the rest of the coastline. The alternative hypothesis is the disturbance by human activities, particularly the influx of tourists (in terms of number of boats) which has been growing continuously in the Scàndola Nature Reserve since the 2000s (see Table VIII). Bretagnolle and Thibault (1993) showed that alarm behaviour (calls, postures, even flight from the nest) by ospreys was evident when a boat approached within less than 250 m of the nest. Detailed observations of boat traffic conducted between July 2013 and 2014 revealed that up to more than 400 tourist boats could pass close to osprey nests (three-quarters of which were within 250 m) in the SNR, during some days in high season. This figure is twice higher than in control areas outside the reserve (Monti *et al.*, 2018a). Secondly, behavioural observations, conducted at osprey nests between 2012 and 2014, showed that local boat traffic induced a significant change in the daily time budget of breeding adults: in the reserve and nearby areas with high boat traffic, the male brought on average half as much prey to the nest, and the female spent three times as much time in alarm behaviour as in more distant, less disturbed areas (e.g. Capicorsu). Finally, feathers taken from chicks at the time of ringing showed levels of corticosterone (which is a stress hormone) 2.5 times higher in chicks from areas with high boat traffic compared to quieter areas in Corsica or elsewhere (Italy, Balearic Islands).

Overall, this analysis combining a demographic assessment, prey ecology, behavioural observations and stress hormones analysis suggests a strong impact of mass tourism-related activities on the local osprey population (Monti *et al.,* 2018a). Demographic simulations based on current survival and breeding success offer a basis for assessment of the chances of survival or extinction of this population over the medium and long term. If nothing changes, the population will continue to decline with an extinction probability of 12 % over 50 years for Corsica and 84 % over 50 years for the SNR (Fig. 37A) (Monti *et al.,* 2018a, 2018e). In order to return to a stable population, it would be necessary to increase the survival probability of juveniles above 55 %, which is a highly unrealistic scenario because juvenile birds spend their first years mainly in the Maghreb, i.e. without effective protective measures. The alternative solution would be to increase female productivity to 1.7 chicks/female/year, which corresponds to the average value recorded in Corsica before 2010 (Fig. 37B). This measure would thus constitute an easily achievable objective, simply by drastically reducing disturbance around the nests.

The annual monitoring of the population and reproduction of the osprey in Scàndula, from 1984 to 2018, constitutes a unique database and long-term series, which strongly supports the scientific conclusions (Thibault and Patrimonio, 1984; Thibault *et al.,* 1985, 1986, 1987, 1988, 1989, 1990; Thibault and Dominici, 1992; Thibault *et al.,* 1993; Thibault and Dominici, 1994; Dominici and Thibault, 1995, 1996; Dominici, 1997; Dominici and Thibaut, 1998; Dominici, 1999, 2000; Dominici and Thibault, 2001, 2002, 2003, 2004, 2005; Dominici, 2007b, 2007c, 2008, 2009, 2010, 2011, 2012; Monti *et al.*, 2018a).

In conclusion, to preserve the osprey, an emblematic species, a symbol of the wild coastline of Corsica, while continuing tourist activities related to the discovery of the Scàndula Nature Reserve in a sustainable manner, therefore in the long term, it is necessary to limit the frequentation by boats and other noisy human activities, at least within 250 m of the nests. Such measures have been enforced around two nests in July 2019 and allowed the fledging of 2 chicks. It should be now extended over the whole of the SNR and for all Corsica nesting sites.

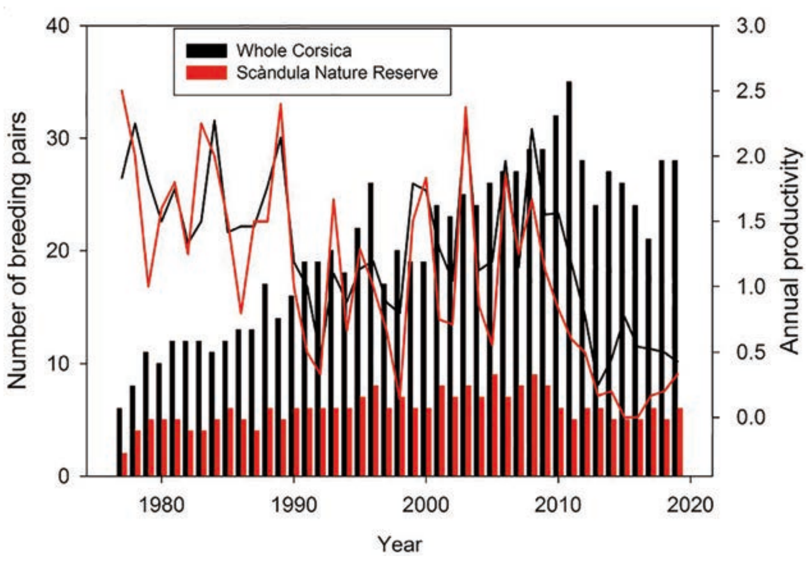

Figure 36. The rise and fall of the osprey in Corsica (in black) and Scàndula Nature Reserve (in red), during the period 1977 – 2019. Bars indicate the annual number of breeding pairs at Scàndula (red) and in the whole of Corsica (i.e. including Scàndula; in black), and the lines represent the breeding success in both areas, estimated as the annual number of chicks fledged divided by the number of breeding pairs (Olivier Duriez and Jean-Marie Dominici, unpublished results).

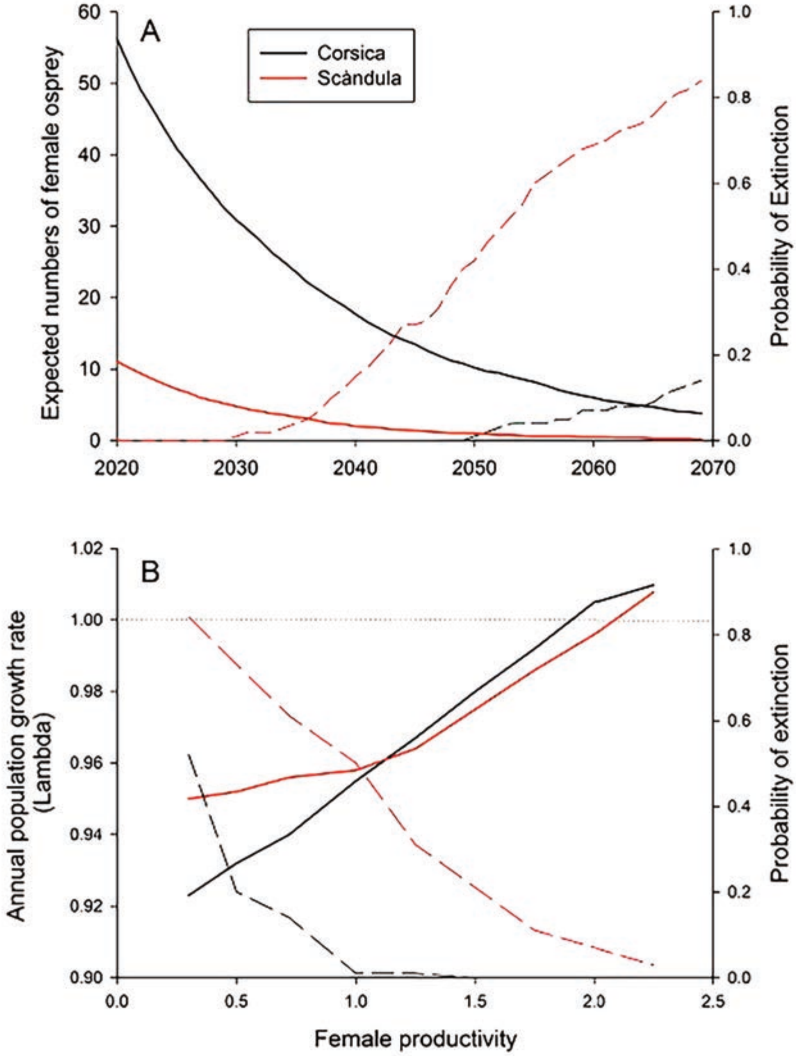

Figure 37. Results of Population Viability Analysis, simulating a population of breeding female osprey, from the life cycle described by Wahl and Barbraud (2014), and applied to the breeding population size in 2019 in Corsica (black) and in Scàndula nature Reserve (red) (Monti *et al.*, 2018e). **Panel A** shows expected female population size (solid lines) and probability of extinction (dashed lines) within a 50-year time frame, if current breeding parameters and survival rates prevail. **Panel B** shows how an increase in female productivity (estimated as number of young females produced per breeding female) would result in an increase in population growth rate (solid lines) and in decrease in probability of extinction (dashed lines). In Corsica, the probability of extinction becomes negligible above a productivity of 1 but the population would start to increase above a productivity of 1.7. At Scàndula, owing the reduced population size, the probability of extinction would be negligible and the population would increase again for productivity values above 2.2.

3.6. The fishes at Scàndula, the reserve effect and the artisanal fishery

3.6.1. Fishes at Scàndula

As far as teleosts are concerned, 142 species have been observed at Scàndula (Antona *et al.,* 1981b; Murgia, 1982; Francour and Finelli, 1991). Their mean biomass, between sea level and 10 m depth, is 56-66 g DM/10 m² (DM: dry mass) (Francour, 1989). Meridional species, such as the grouper *Epinephelus costae* (= *E. alexandrinus*) and *Mycteroperca rubra*, pushed northwards by sea water warming, are more and more common (Meinesz *et al.,* 1990; Cottalorda *et al.,* 2012).

The parasites are more often regarded very negatively by the general public: they imagine that the presence of parasites constitutes a disturbance. Yet it is quite the opposite: parasites, like predators, constitute an essential compartment for the functioning of healthy ecosystems (Combes, 1995; Bartoli, 2003; Bartoli and Boudouresque, 2007; Boudouresque and Thibaut, 2018). Bartoli (1987, 1988, 1990), Bartoli and Gibson (1991) and Bartoli *et al.* (2005) have shown that, for fish parasites, the Scàndula reserve is the richest region in the whole Mediterranean, which reflects the good functioning of its ecosystems. As has been demonstrated for other marine ecosystems, the greater the biodiversity and the maturity of the ecosystem, the greater the diversity and abundance of parasites (e.g., Hudson *et al*., 2006). In the teleost *Symphodus ocellatus*, three species of digenes may be present, their number increasing with the age and social status of the fish (Bartoli and Riutord, 1994). A new species of digene, *Genitocotyle mediterranea*, has been described from Scàndula (Bartoli *et al.,* 1995). Parasites of the sea gull were also studied (Bartoli, 1984).

3.6.2. The reserve effect

In a protected area, and in adjacent areas, a number of changes occur (compared with the situation prior to protection); these changes are referred to as the'reserve effect' (Fig. 38) (e.g. Halpern and Warner, 2002; Ward and Hegerl, 2003; Boudouresque *et al.,* 2005; Shepherd and Myers, 2005; Myers *et al.,* 2007; Lester *et al.,* 2008; Stobart *et al.,* 2009; Ojeda-Martínez *et al.,* 2011; Le Diréach *et al.,* 2018; Raimbault *et al.,* 2021; Sala *et al.,* 2021). As highlighted by Sala *et al.* (2021), MPAs, especially strongly protected areas, can be effective management tools to safeguard and restore marine biodiversity and associated services, complement conventional fisheries management and contribute to the mitigation of climate change by protecting the carbon stored within sediments (soft bottoms and seagrass *matte*) from being re-mineralized and released as CO_2.

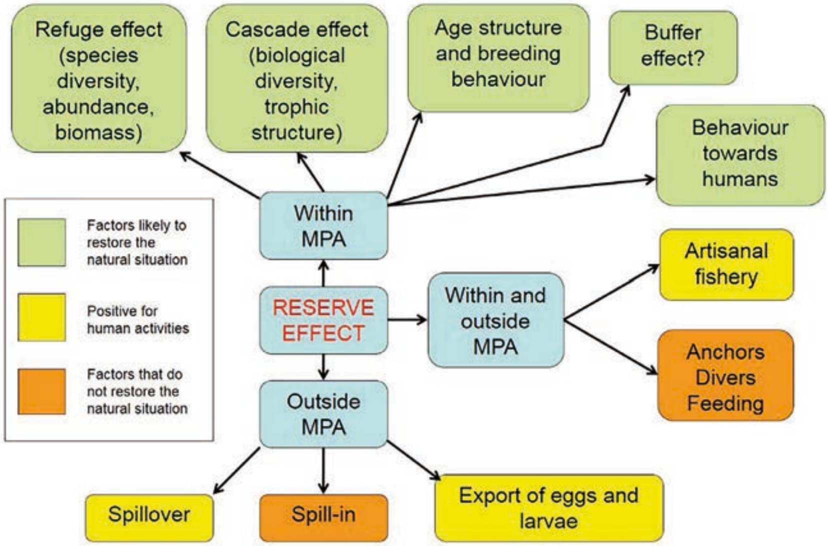

Figure 38. The reserve effect and its different components. Charles-François Boudouresque, original drawing.

The cascade effect is one of the processes that are referred to as the reserve effect. The principle is simple: in the trophic chain, if top predators are abundant, they reduce the abundance of intermediate level predators, which increases the abundance of lower level predators, reduces that of herbivorous species and the small fauna of invertebrates and finally increases primary producers (Sala *et al.,* 1998a, 1998b). In the real world, it is often more complicated, especially because ecosystems are not structured by food chains, but by much more complex food webs (Sala *et al.,* 1998a; Steneck, 1998). For the general public, in a protected area (because they mainly look at fishes), all species are more abundant: they do not perceive the cascade effect (especially on invertebrates); obviously, if the predators are more abundant, the prey are relatively less abundant or less active (e.g. Sala and Zabala, 1996; Guidetti, 2006; O'Sullivan and Emerson, 2011). It is in Scàndula that the extreme rarity of invertebrates (sea urchins, molluscs, etc.) in the NTZ (No-Take Zone) and in the buffer area was demonstrated (Table III; Boudouresque *et al.,* 1992b).

The historical fish surveys performed in the Côte Bleue Marine Park (Le Diréach *et al.,* 2017), in the Port-Cros National Park (Astruch *et al.*, 2018a), in the Calanques National Park (Le Diréach *et al.*, 2020), in Provence, and in the Cabo de Palos-Islas Hormigas MPA (Rojo *et al.,* 2021) have demonstrated that the abundance of large fishes (including top predators) within enforced MPAs is necessarily sustained by a significant presence of each level in the trophic chain. That is why the assertion of a depletion in fishes due to the increased abundance of the emblematic grouper (*Epinephelus marginatus*) in several NTZ still figures among erroneous representations of predation relationships in the marine environment. Grouper abundance is an indicator which testified of the "good health" and the stability of the fish community (Harmelin-Vivien *et al.,* 2007) and groupers are abundant in the NTZ of SNR.

Table III. The cascade effect within the Scàndula Nature Reserve (SNR) and outside: benthic marine invertebrates (mainly echinoderms, molluscans and crustaceans). Md = missing data. From Boudouresque *et al.* (1992b).

Site	Parameter	1988	1989	1990	1991
Galeria (outside the SNR)	Number of species (alpha-diversity)	17	16	13	20
	Mean number of individuals/m²	4.1	5.5	5.0	5.8
	Shannon's diversity H'	1.70	1.85	1.56	1.92
	Pielou's eveness J	0.41	0.46	0.42	0.45
Cala Petraghja (within the SNR)	Number of species (alpha-diversity)	md	7	7	12
	Mean number of individuals/m²	md	0.5	0.3	0.6
	Shannon's diversity H'	md	2.45	2.28	3.08
	Pielou's eveness J	md	0.87	0.81	0.86

As Port-Cros National Park, the Scàndula Nature Reserve is one of the Mediterranean MPAs with a limited surface area of NTZ (82 ha) but enforced protection. Recreational fishing (angling and spear fishing) is strictly banned in the partial reserve while artisanal fishing is allowed with some regulation (see below). Francour contributed to demonstrating the positive impact of protection on Mediterranean fish assemblages in SNR in 1988 (Francour, 1991), when comparing sampling sites situated down to 25 m depth within the NTZ, in the partial reserve and outside, in seagrass meadows and reef habitats. Those results appear among the first demonstrations of the increase in the number of species, of density, biomass and demographic structure of fishes in Mediterranean MPAs after the studies of Harmelin-Vivien (1982) and Harmelin (1984) in Port-Cros (Provence) and Bell (1983) in Banyuls-sur-Mer and Cap Béar (French Catalonia). The presence of large grouper (*Epinephelus marginatus*) and brown meagre (*Sciaena* *umbra*) at Scàndula was noteworthy at that time given their rarity before the introduction of a moratorium banning recreational fishing of grouper in Corsica in 1983 (this moratorium was extended to mainland France in 1993). The fish community of the SNR was studied from 1989 to 1999 (Francour, 1994, 2000). The dominant families (labrids and sparids) do not have the same sensitivity to anthropogenic disturbances. Scàndula started to build its reputation as a hotspot for large and noble fishes, mostly carnivorous 'top predators' (*Dicentrarchus labrax, Sparus aurata, Epinephelus marginatus, Sciaena umbra, Dentex dentex*) and as a reference site for fish specialists in marine science.

The iconic fish in Mediterranean coastal habitats, the brown meagre *Sciaena umbra* (Fig. 39), which is particularly vulnerable to fishing pressure, including angling and spearfishing, was surveyed by scuba visual census: biomass and abundance were significantly higher in the integral reserve than in the unprotected areas (Table IV). In addition, between 1983 (eight years after the establishment of the Scàndula Nature Reserve) and 2012, the number of individuals within the integral reserve increased by a multiple of 1.8 (at Palazzu) and 5.7 (at Gargalu), indicating a continuous long-term effect of protection on this fish species. An exceptionally large specimen of the brown meagre *Sciaena umbra*, seized after a poacher was arrested in the No-Take Zone of Scàndula, provided an opportunity to estimate its age, on the basis of its otoliths: 31 years old (Morat *et al.,* 2017).

Figure. 39. A school of more than a dozen individuals of the brown meagre *Sciaena umbra* at Punta Palazzu (SNR) in April 2019. Photo © GIS Posidonie.

Table IV. Mean abundance (fish/750 m², ± SD) and mean biomass (g/750 m², ± SD) of the brown meagre *Sciaena umbra* in 2012, according to the level of protection. Letters (a, b) indicate significant differences of means ($p < 0.05$) (Kruskal-Wallis post-hoc test). From Harmelin-Vivien *et al.* (2015), modified.

	Abundance	Biomass
Integral Reserve (No-take zone)	2.57 (± 7.38) a	2 409 (± 7 707) a
Partially protected zone (buffer zone)	1.16 (± 3.94) ab	769 (± 2 544) ab
Unprotected zone	0.15 (± 1.26) b	83 (± 660) b

As a consequence of the banning of the recreational fishing of *S. umbra* in France (since 2014 and 23/12/2013 in Corsica), the density of the brown meagre also increased outside the SNR (Cottalorda *et al.,* 2019). This was confirmed by the catches from artisanal fishing: the brown meagre *S. umbra* were 6 times more abundant in the catches outside the SNR (north of Punta Ciuttone for example) in June 2018 than before the banning of recreational fishing (data from the 2018 survey of Le Diréach *et al. in* Cottalorda *et al.,* 2019). However, the brown meagre and the grouper recently declined in the NTZ, without any obvious cause; hypotheses are **(i)** a shift of the populations toward deeper habitats or migration outside the NTZ, **(ii)** poaching in the buffer zone or in the NTZ, **(iii)** mortality linked to a nodavirus as has been observed in the eastern Mediterranean (Libya) or in southern Italy (Vendramin *et al.,* 2013; Rizgalla *et al.,* 2016).

The positive effect of the enforced protection in the SNR (higher density and higher fish biomass in the NTZ) was recently confirmed in 2018-2019 (Astruch *et al.*, 2018b, 2019), when a study of the frequentation was an opportunity to update the quantitative estimates of fishes in Palazzu and Gargalu (NTZ), Les Orgues and Sulana (buffer zone), Porri and A Caletta (unprotected zone, outside the SNR). The potential effect of noise pollution was masked by the effects of protection, the quality of the habitat and the seasonal variations. Higher densities of grouper and brown meagre were observed in October (low season) than in August (high season), but evidence of a real impact of noise from boats on the fish populations was difficult to assess, without long-term data on fish abundance at the same sites and the number of boat passages at the same sites.

The **buffer effect** has been proposed by Francour (2000) and Francour and Bodilis (2004) on the basis of research carried out at Scandula (Table V). It corresponds to an attenuation of interannual variations and a greater rate of recovery in fish populations of *Posidonia oceanica* meadows after a disturbance. This effect is consistent with the theory that high species diversity enhances ecosystem performance (Naeem and Li, 1997), a theory that is not universally accepted. However, the buffer effect is uncertain and requires additional research (García-Charton *et al.* (2008).

Table V. The coefficient of variation, a proxy of population stability (buffer effect) of main fish families, sampled between 1989 and 1999 within the Scàndula Nature Reserve (NTZ and buffer area) and outside. From Francour and Bodilis (2004).

	Outside	Buffer area	NTZ (No-Take zone)
Labridae	0.57	0.59	0.38
Sparidae	0.47	0.51	0.38
Serranidae	0.33	0.34	0.41
All fish families	0.41	0.34	0.24

The beautiful and luminous seascapes of the SNR shallow waters (sea surface to 5 m depth) started to be explored in September 1992 by Francour and Le Diréach (1994, 1995, 1996) and Le Diréach and Francour (1998). The question was to find which fish species were present as juveniles in the *P. oceanica* meadows and the small blocks and sandy bottoms, especially at L'Elbu and Gattaghja, and whether their density was higher in the vicinity of the MPA. Microhabitats and home range of labrids and serranids (*Diplodus annularis, Coris julis, Symphodus* spp., *Serranus* spp.) settlers (juveniles) were described by Le Diréach and Francour (1998) *via* visual census, in the framework of the SETMORT European program. Data showed that the settlement intensity was space-, season- and species-dependent (*Diplodus* spp.) in Spain, mainland France and Italy, but that the characteristics of their recruitment habitat were the same everywhere (Vigliola *et al.,* 1998). The protection level at Scàndula did not influence the density of juveniles, but some patterns of exportation were suspected to be downstream, from the south (SNR sites) towards the north (outside SNR) because of the advection due to the dominant current (Table VI) (Harmelin *et al.,* 1998; Boudouresque *et al.,* 2005).

Investigation of juvenile fish microhabitats and mortality at settlement stage, and their nursery value (*sensu* Beck *et al.,* 2001) was developed by Cheminée (2012) and Cheminée *et al.* (2016). In Scàndula, reef habitats with seaweed forests (*Cystoseira crinita* and *C. brachycarpa*) have a high nursery value for littoral fishes of ecological and economic importance. The loss of these forests (see above and

Verlaque *et al.,* 1999a; Ballesteros *et al.,* 2002) may strongly affect the recruitment of coastal fish (Cheminée *et al.,* 2013; Thiriet, 2014). At seascape scale, Cheminée *et al*. (2017) have demonstrated in the SNR that the mosaic of habitats in shallow reefs of the NW Mediterranean may be more productive than a single habitat, because of the complementarity of habitats, synergy between them (edge effects) and the nursery role of the macrophyte cover. At a wider spatial scale, oceanographic patterns are driving recruitment processes but at a finer spatial scale, structural complexities may affect the quality of juvenile settlement (Cheminée *et al.;* 2016; Thiriet, 2014; Thiriet *et al.,* 2016).

Table VI. Density (number of individuals per 10 m²) of juveniles of *Diplodus annularis* upstream, inside and downstream from the SNR, alongside the prevailing current. After Francour and Le Diréach *in* Harmelin *et al.* (1998) and Boudouresque *et al.* (2005).

Direction of the prevailing current	Locality	Status of protection	Density of juveniles
North ↑	Bay of Galeria	Outside the reserve	1.12
↑	Bay of L'Elbu	Partially protected zone	0.47
↑	Gargalu	NTZ (No-Take Zone)	0.34
South ↑	Gulf of U Portu	Outside the reserve	0.22

3.6.3. Artisanal fishery at Scàndula (SNR and adjacent area)

Worldwide, with a very few exceptions, marine reserves benefit local artisanal fishery, i.e. small-scale fishery (SSF) (Russ *et al.,* 2004; Boudouresque *et al.,* 2005; Sala *et al.,* 2021): higher CPUEs (Catch per Unit Effort) and lower fishing effort (therefore less expensive), higher total catch (despite reduction of the fishing area), larger catch of 'noble fishes' (therefore higher selling price), etc. (Russ *et al.,* 2004).

The artisanal fishery plays an important socioeconomic role in Corsica. It fits into the category of SSF (see Miniconi, 2000; Pere, 2012) which are defined as '*fishing carried out by fishing vessels of an overall length of less than 12 m and not using towed fishing gears*' according to the new European Union Common Fisheries Policy. In the absence of an industrial fishery and of major sources of pollution, Corsica therefore appears in the Mediterranean Sea as an ideal area to assess the effect of artisanal fishing (Gobert *et al.*, 2020). Among the 188 '*petits métiers*' fishing boats recorded in Corsica (source: DIRM at 30/10/2015), 15 are exclusively fishing between Calvi and Carghjese, 15 are regular and 11 occasional. Their fishers belong to the *prudhommies* of Calvi/

Ile Rousse (L'Isula) or Ajaccio (Ajacciu) and are distributed among 10 harbours or landing sites (Uffiziu di l'Ambiente di a Corsica, 2016). The local small-scale fleet working around the SNR encompasses 2 large boats of 12 m length and about 10 smaller traditional fishing boats or outboard motor boats (6-8 m length) (Préfet de Corse, 2021).

SSF vessels use a wide variety of fishing techniques, mostly passive gears (nets, long-lines or traps), to target the seasonal resources of the SNR from 0 to 350 m depth: 'fine' fishes (osteichthyans) and spiny lobster (*Palinurus elephas* and *P. mauritanicus*). This fishery is characteristic of the multi-use and multi-specific artisanal fisheries encountered around the Mediterranean coasts. The catch is variable according to seasons, but the long-term fishing survey started in 2000 (Le Diréach *et al.*, 2002) has demonstrated that the number of vessels has been almost stable for 20 years in the SNR.

Figure 40. Traditional trammel net used from a Galeria fishing boat. Photo © GIS Posidonie.

The fishing season lasts 8 months (from March to October) with a summer peak of activity (May to September) (Pere, 2012; Le Diréach, 2013; Le Diréach *et al.,* 2019). During the spring season (March to May) the main targets are fishes. From June to September, spiny lobster fishing is more intensive. From September to the end of the fishing period, the red mullet *Mullus surmuletus* is the main target species (Pere, 2012; Le Diréach, 2013; Le Diréach *et al.*, 2013). Traps and long lines are seasonally used by some fishers but fishing with nets (trammel nets or gill nets) is the most widespread practice throughout the year (Fig. 40). Large mesh size targets spiny lobster (*P. elephas*), *Lophius piscatorius* and *Scorpaena scrofa* from 30 to 120 m depth. Medium mesh size is used for nets targeting the 'fine' fishes or 'white' fish: mainly sparids (*Diplodus* spp., *Spondyliosoma cantharus*, *Pagellus* spp., *Pagrus pagrus*, but also the brown meagre *Sciaena umbra* and *Phycis phycis*. Small mesh size is used to catch red mullet (*Mullus surmuletus*) in spring and mostly in autumn with trammel nets set for only 3 to 5 hours early in the morning or before dawn.

From time to time, during spring or summer good weather days, large boats come from Ajacciu and stays several days to fish on the Scàndula fishing grounds (including the buffer zone of the SNR). These boats are not really welcomed by local fishermen managing their fishing effort on the basis of a mutual understanding with each other and respecting the fishing regulations of the partial reserve: **(i)** only nets, long lines and traps are allowed for fishing; **(ii)** using simultaneously nets and long lines is prohibited; **(iii)** the number of net pieces (100 m) is limited to 40 per boat (i.e. 8 nets of 500 m maximum); **(iv)** the surface signals must carry the boat registration number; **(v)** the fishing duration for nets cannot exceed 48 h and the nets have to be shifted when removed. Local professional boats have a permanent authorization for fishing in the buffer zone (8 boats) or a temporary permit (7 boats) delivered annually by the manager of the SNR. A maximum of 8 boats are allowed to fish simultaneously in this area where recreational fishing is totally banned. The vessels are owner-operated, fishers are alone or benefit from the help of one sailor (sometimes a younger fisherman training onboard). The fishing product has a high unit value (as usual in the Mediterranean SSF) and is allocated to local restaurants (in Galeria, Ghjirulatu, U Portu) or sold in Ajacciu, L'Isula or Calvi markets. There is little local selling for inhabitants (for a couple of years, fish has been sold in the Galeria market).

The intensity of fishing is variable on this part of the western coast of Corsica (Pere, 2012). But this author considers that the SNR is one of the most intensively fished zones (fish nets) of the sector Calvi to Carghjese, with the Gulf of Ghjirulatu, the northern coast of the Gulf of Portu and Capu Rossu (between 0 and 50 m depth). For spiny lobster nets, the most exploited sectors are the northern coast of the Gulf of Portu and Capu Rossu (50-100 m depth).

On the western coast of Corsica, the gulfs and bays are important fishing zones because of the narrowness of the continental shelf; as a result, a small surface area remains available for fishing. Around the SNR, habitats are favorable to a variety of fish species. The fishing monitoring has shown a seasonal shift to deeper grounds (>50 m), in summer, when fishers target the spiny lobster. The distribution of gear does not evidence any concentration close to the NTZ or in the buffer zone (partial reserve) (Fig. 41). The proportion of nets set within the partial reserve remains at the same low level since 2000 (about 12 %) and the distribution of gear is linked to habitats and the seasonal distribution patterns of fishes. It may increase in autumn and reach 25 %, in summer during the tourist saison, when fish is also targeted with '*battude*' (see below).

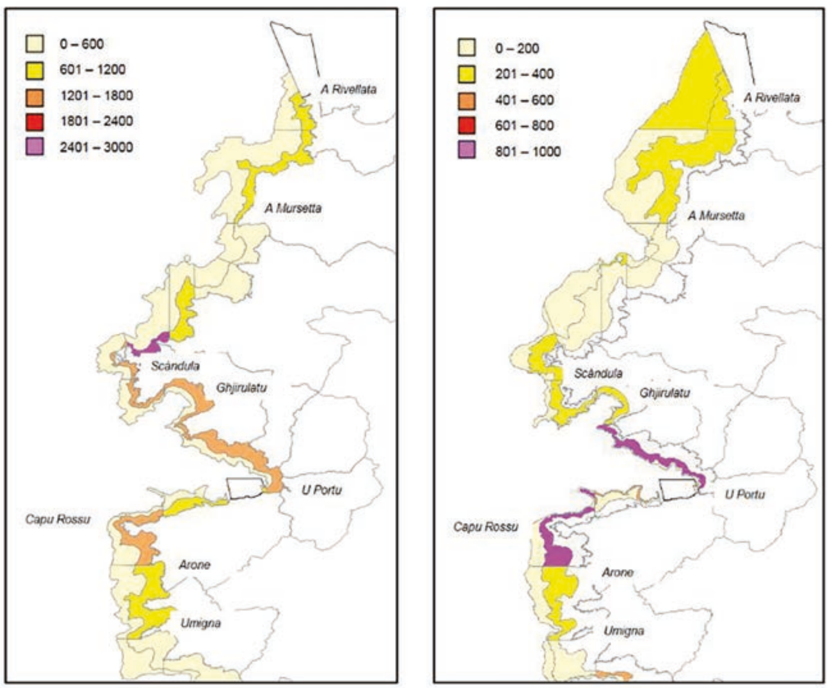

Figure 41. Annual fishing intensity (number of net pieces 50 m long/km²), between Calvi (North) and Carghjese (south). Years 2004 to 2011. Left: fish nets. Right: spiny lobster nets. From Pere (2012) *in* Uffiziu di l'Ambiente di a Corsica (2016). Apparent discrepencies between fishing intensity (fish nets) and other results (see Fig. 39) could result from a different mode of calculation.

The mean number of boats fishing in the sampling area (from Galeria to Capu Seninu) was 6.0 (SD=1.6) and varied from 2.6 to 7.8 during the 12 surveys, from September 2000 to May 2018. The mean number of gear recorded per sampling day (22.2; SD=7.3) is higher in summer since 2006 (27-29) than before 2006 (19), but was only 4.7 in May 2018 (Le Diréach *et al.*, 2019). The mean length of nets used per fishing boat has increased since 2007 from 333 to 501 m (Le Diréach *et al.*, 2013). The practices observed around the SNR do not evidence an increase of the fishing effort in terms of boats and number of gears (Figs. 42, 43), but no decrease either as evidenced by Pere (2012) for the sectors Calvi-San Fiurenzu and U Portu-Sagone. However, like everywhere in the Mediterranean, changes in fishing practices have resulted in an increase in the fishing effort: **(i)** the use of a fishing winch to pull the nets on board – more nets during the same day or deeper grounds utilizable; **(ii)** the use of single or multi-strand nylon nets, less selective (in addition, these nets are cheaper, ready to use and cannot be repaired); and **(iii)** the use of better depth sonar. This mechanization represents a progress with regard to the working conditions but it is responsible for an increase in the fishing effort since 2000, despite the slight change in the mean number of boats and the mean number of nets. As compared to trawling (prohibited in the SNR and not operable on the western rocky coast of Corsica), those fishing practices are considered to have low impact on habitats, but as in similar coastal habitats, fishing with nets upon SNR coralligenous habitats (when targetting spiny lobster or fish living between 40 and 120 m depth) implies some damage to gorgonians and other benthic sessile species, which are pulled up by nets. Total by-catch and discards were estimated at between 5 and 27 % of the net-caught fish biomass, according to the season. This concerns mostly Chondrichthyans, which are caught in fish nets with large mesh size (4 to 5) or medium mesh size (6 to 8) (Le Diréach *et al.*, 2013), or species of low market value.

Despite the reasons to consider that the fishing effort is high, production is probably high too. The surveys carried out from 2001 to 2013 (Le Diréach *et al.*, 2015) show seasonal and interannual variations in the yield estimations of nets and a high diversity in the catches of the artisanal fishers, but no decrease in the mean yield over the monitoring period. The best total CPUE (catch per unit of effort) were observed in spring (3.0 to 3.8 kg WM/100 m of nets; WM: wet mass). The mean CPUE for fish is estimated at between 1.8 and 3.5 kg WM/100 m and for spiny lobster at between 0.36 and 0.66 kg WM/100m of nets (Table VII).

Since June 2011, nets set very close to the coast, with one end attached to a rock, named '*battudes*', were specifically sampled; they showed a mean yield of 5.8 to 8.4 kg WM/100 m of nets, considerably higher than the yield of other nets. This type of arrangement of the nets, well adapted to shallow bottoms of the SNR and the neighbouring reserve area, is easy to deploy with small boats and provide fishes (mainly sparids, brown meager *Sciaena umbra*) of an ideal size for the restaurants during the tourist season.

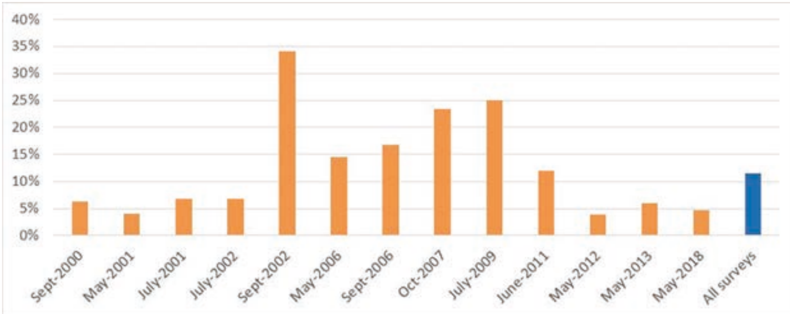

Figure 42. Proportion of gears, from Galeria (north) to Capu Seninu (south), set in the partial reserve (SNR) at each campaign of the seasonal fishing survey (2000 through 2018). A net is considered as fishing in the partial reserve when more than 50 % of the gear is within it. In 2002, the spiny lobster fishing season stopped on August 31st; as a consequence, all the fishing effort has been allocated to fishes in September 2002.

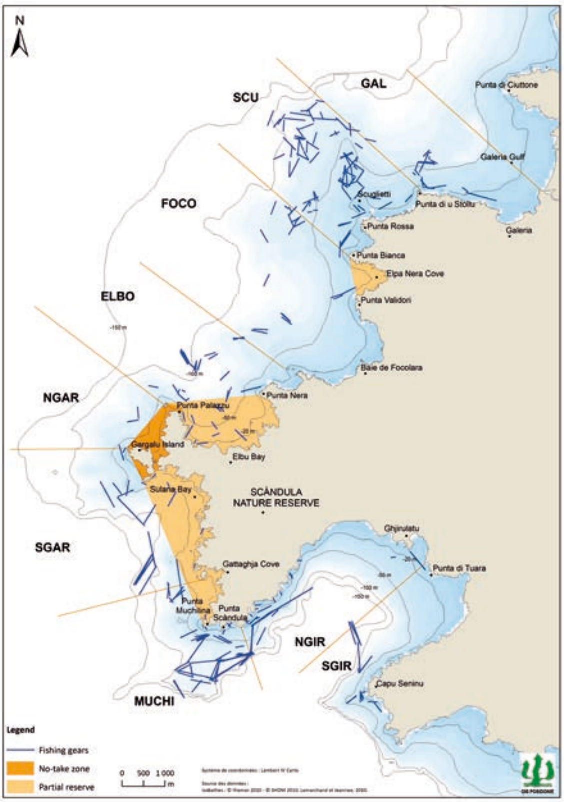

Figure 43. Distribution of the fishing gear (blue lines; 267 gears-day sampled in 9 days) during the survey of May 2013. Fishing zones (north to south): Galeria (GAL), Scuglietti (SCU), Focolara (FOCO), L'Elbu (ELBO), North Gargalu (NGAR), South Gargalu (SGAR), Muchilina (MUCHI), North Ghjirulatu (NGIR) and South Ghjirulatu (SGIR). The SNR encompasses the sectors of ELBO, NGAR, SGAR and MUCHI, in addition to the Elpa Nera Cove (within the sector FOCO).

Table VII. Mean CPUE (Wet mass – WM – in kg per 100 m of net length, and standard error) for each seasonal campaign in the SNR and the surrounding area (from Galeria, north, to Capu Seninu, south), for fishes and the spiny lobster *Palinurus elephas*. The other crustaceans and cephalopods are not reported here. The *battudes* nets have been removed from this set of data. From Le Diréach *et al*. (2015).

Campaign	Number of sampled nets (fish)	Total wet mass (WM)	Wet fish mass (WM)	Number of sampled nets (spiny lobster)	Wet spiny lobster mass
April 2001	34	3.0 (4.0)	2.3 (4.1)	20	0.44 (0.62)
July 2001	29	2.4 (2.0)	2.0 (1.9)	14	0.50 (0.36)
July 2002	57	1.9 (2.0)	1.6 (1.9)	21	0.43 (0.44)
September 2002	24	1.0 (0.7)	1.0 (0.7)	-	Fishing closed
May 2006	63	3.5 (3.1)	3.1 (3.0)	13	0.63 (0.70)
September 2006	54	2.3 (1.5)	2.0 (1.5)	11	0.71 (0.80)
October 2007	29	1.8 (1.9)	1.8 (1.9)	-	Fishing closed
June 2011	70	2.2 (3.1)	1.8 (3.1)	18	0.78 (0.46)
May 2012	57	2.7 (2.4)	2.4 (2.4)	31	0.18 (0.26)
May 2013	66	2.4 (2.7)	2.0 (2.3)	33	0.31 (0.32)

Several factors can explain the high level of CPUE in the SNR and the neighbouring reserve area: the relatively low number of local fishing boats in Galeria, Ghjirulatu and U Portu, as compared to mainland France, and the long distance between the SNR MPA and other and more important fishing harbours like Calvi and Ajacciu. On the western coast of Corsica, the waves and the sailing conditions are determined by the dominance of the winds from the north-westerly and south-westerly direction, which, most often, result in difficult sailing conditions and hard working conditions onboard. This rocky coast is unsuited to leisure boats and recreational fishing, and in addition the number of available days for artisanal fishing is limited by the meteorological conditions (the so-called 'biological rest period' in Corsica). Moreover, there is no trawling on the western rocky coast of Corsica and no seine boat working close to the coast, such as can be seen along the Marseille coast, and which catch a major part of the coastal fish production. These specific conditions could explain the relative stability of the yield of fishing nets observed in the SNR and surrounding area so far.

Despite of the arrival of a few young fishermen with varying levels of knowledge about the fisheries, during the last decades, the modernization has not led to a loss of some traditional ecological knowledge possessed by the older local artisanal fishers. More or less the same fishers have been working in this area since the beginning of the survey in 2000. They are using the same multi-specific fishing techniques, year-round, that provides diversity in the catches and some turnover between profitable fishing grounds. The fishing strategies are still driven by the seasonal rhythms of fish localization and fishermen reach some agreement in sharing the fishing places. Some fishing spots are subject to a high seasonal effort, such as Argentella Bay, Scuglietti rocks and Punta Muchilina for fish in late spring and the south of Gargalu Island for spiny lobster in summer. In the area surrounding the SNR, the competition between recreational and artisanal fishing is much lower than anywhere else in the Mediterranean (Lloret *et al.*, 2018). The protection system in the SNR, with a small no-take-zone (NTZ), bordered by a buffer zone where recreational fishing is banned, includes the regulation of artisanal fishing by a *numerus clausus* (we have seen before that the number of artisanal fishers allowed to practice in the same area and at the same time, and also annually, is limited). The Port-Cros Archipelago MPA (core of the Port-Cros National Park, Provence) also has a limited number of fishermen allowed to fish; the establishment of a *numerus clausus* is uncommon in northern Mediterranean MPAs but seems to be effective. Elswhere, a high fishing pressure is often observed within partial reserves, precluding exportation benefits from the NTZ (see Claudet *et al.*, 2008; Stelzenmüller *et al.*, 2008), but in SNR habitats are more suitable for fishing outside of the partial reserve. Moreover, the fishing effort is often higher along the border of the MPAs ('fishing the line') and leads to an inflexion in the biomass gradient between the NTZ and adjacent areas (Goñi *et al.*, 2008), which has not been evidenced during the fishing survey of the SNR.

Despite no fishing management plan nor ecosystem-based principles or agrement on decisions related to SSF, the artisanal fishery in the SNR and adjacent area seems to still be sustainable, so far. But times are changing. This is probably a fragile equilibrium because it relies on relationships between people and the respect of local uses among fishermen. Self-regulation between fishermen and collaboration between the managers of the SNR and the fishermen are playing an important role, even if an informal decision process is used for management measures of fishing concern. This is not a co-management as promoted by the Medpan organization or in the literature during the last decade (Di Franco *et al.*, 2016), but it has worked for the last decades. In other places in France, small-scale coastal fisheries undergo tensions mainly due to young people coming to the '*métier*' without any fishing training or environmental knowledge or not being familiar with or failing to stick to local commitments or codes between fishers. Sometimes these people may be attracted by the notion of self-reliance in work, but they often underestimate the workload and the time necessary to acquire the required knowledge and achieve profitability. The success of artisanal fisheries relies on the seasonality of practices, which means: multiple targets, multiple gears, never deploying the gear for several days in the same place and a knowledge of the fish life cycles. The majority of fishermen working within and around the SNR have this knowledge and they have had the good fortune to not be too numerous over the past twenty years. Hence, they have so far avoided hard competition, which is increasing everywhere else. The management and enforcement in the SNR has contributed for years to limiting poaching and competition with recreational fishing. That is why SSF have probably succeeded in sharing resources and ensuring their renewal. Nevertheless, fishing for coastal fish is a practice that is on the increase in summer, the spiny lobster season is starting earlier, the shallow waters are more often exploited with small mesh size nets even outside the red mullet season, when targeting fish for soup. These behaviours betray a search of greater profitability whilst the number of boats, of nets, and the length of nets, have not been significantly increasing over time.

4. Threats to the biodiversity of Scàndula

4.1. Tourist frequentation

Over-frequentation is a general problem in regions attractive to tourists, which is the case in the Mediterranean. It generates complex conflicts between users, between stakeholders, and between users, stakeholders and managers. In protected areas, these conflicts are exacerbated by the attractiveness of exceptional landscapes, which is the case with Scàndula, or by supposedly paradisiac beaches, which is the case with Port-Cros and Porquerolles (Port-Cros National Park, Provence, France) (Barcelo *et al.,* 2018; Deldrève *et al.,* 2019; Cadoret, 2021).

The number of visitors to Scàndula was almost nil in the 1950s and 1960s, and has increased considerably since the creation of the reserve in 1975. The senior authors of this article experienced an almost deserted Scàndula Nature Reserve in 1975. Sightseeing boat trips gradually increased, starting from Galeria and especially Calvi to the north (about 30 km as the crow flies), U Portu (20 km), Carghjese (30 km) and Ajacciu (60 km) to the south, to now constitute a serious problem (Table VIII) (Richez and Richez Battesti, 2007; Anonymous, 2020). From the 1980s onwards, competition between sea trip companies was severe (Richez and Richez Battesti, 2007). In the mid-2000s, the number of visitors *via* boat trips was estimated, by the staff of the SNR, based on *in situ* counts, between 190 000 and 200 000/year (Richez and Richez Battesti, 2007). A more accurate estimate, based on 2012 data, was 150 000 visitors per year *via* organized boat trips plus 50 000 *via* pleasure boats (Luciani, 2016).

Until 2019, quantitative data on visits to the SNR by boats was fragmentary and unreliable. **(i)** MEDOBS (*Observatoire aérien des usages en Méditerranée*) data, based on occasional and irregular aerial overflights, are unusable (Schohn *et al.,* 2019a). **(ii)** In the SNR, the Google Earth software offers the possibility of viewing four satellite images dating from Friday August 7, 2009, Friday October 28, 2016, Monday June 12, 2017 and Sunday June 31, 2017. All boats can be identified according to different categories (sailing boat, motor boat or jet-ski) and divided into different size classes (Fig. 44). Unfortunately, as for MEDOBS data, satellite images from Google Earth are too occasional (Schohn *et al.,* 2019a). **(iii)** The AIS (Automatic Identification System) is an automated message exchange system between ships by VHF radio which allows ships and traffic monitoring systems to know e.g. the position, name, destination of ships. Unfortunately, this system only applies to certain vessels (e.g. > 300 deadweight tonnage, > 24 m), so most pleasure craft are not included. Over eight years (2010 through 2018), only 200 boats were registered by AIS between Galeria and Ghjirulatu. (Schohn *et al.,* 2019a). **(iv)** Finally, the On-Board Counting Method (OBCM), resulting from the French PAMPA-LITEAU program (Le Diréach *et al.,* 2011; Pelletier *et al.,* 2011) was used at Scàndula. During each outing, the boat of the Reserve warden's boat sails through the entire area, following an identical route; the type (e.g. sailing boat, rigid inflatable boat), size and position of the vessels are noted. The method is effective, but time consuming, especially since the wardens also have surveillance, public information and scientific research tasks (Schohn *et al.,* 2019a).

Table VIII. Boat trips to Scàndula. From Richez and Richez Battesti (2007) and original data for 2020. The number of visitors per day is not the multiplication of the number of seats by the number of boats: (i) some of the seats may not be occupied; (ii) some boats make several trips per day; (iii) depending on the sea state, some days some of the boats do not go to sea. (iv) Scàndula is not the only destination for some boats. md: missing data.

Years	1956	1976	1988	1990	2006	2020
Number of boats	2	3	7	8	13	>30 [a]
Number of seats	75	178	768	889	1 395	md

[a] 30 boats at U Portu. The total number of boats (from Calvi to Ajacciu) could be close to 80-100.

Figure 44. Counting, identification and measurement of the length of the boats in L'Elbu marina (*marina* in the Corsican sense), from a Google Earth satellite image taken on Friday August 7, 2009.

Using a Self-Activating Photographic Device (SAPD), with cameras installed near the Genoese towers of L'Elbu and Gargalu, attendance rates at L'Elbu Bay by boats have been quantified and identified by type (Fig. 45) (Dossmann, 2019; Schohn *et al.,* 2019b). From early April to early October 2018, 11 065 boats were observed at L'Elbu Bay, including 1 369 anchored boats (Fig. 46) (Dossmann, 2019; Schohn *et al.,* 2019b). If we consider that, on board a pleasure boat, there are on average 5 people (Le Berre *et al.,* 2009), this represents ~55 000 visitors; however, sightseeing boats can accommodate up to a hundred tourists, and taking them into account could multiply that figure by a factor of four, which would be consistent with Luciani's assessment (Luciani, 2016).

Most of the boaters who frequent the SNR are familiar with its status and regulations. They would even accept a tightening up of the constraints, for example the ban of anchoring (Richez, 1992; Schohn *et al.,* 2019a).

In August 2019, 130 (± 95, SD) sailing boats per day (between 6:00 am and 9:00 pm) were observed by the Gargalu DPDA in the Gargalu-Palazzu pass (Schohn *et al*., 2019a). This represents, on average, the passage of one boat every 7 minutes in this restricted area. In addition, image analysis shows that 20% of these boats sailed at excessive speed, which could have negative environmental impact (Schohn *et al.,* 2019a). Frequentation by boats causes the flight of the neighbouring ospreys (Fig. 47).

Figure 45. Image synthesizing (from April 1st, 2018 to August 31st, 2019) the boats at anchor in the bay of L'Elbu, seen from the camera (SAPD) at L'Elbu tower. Each purple line represents an anchoring boat and its movements for the duration of the anchorage. On the far left, the beach at L'Elbu *marina*. In the background on the right, Punta Palazzu. From Schohn *et al.* (2019a).

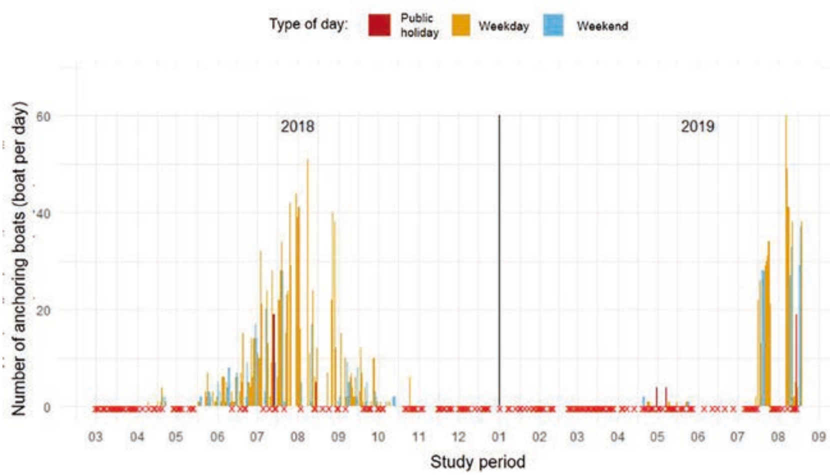

Figure 46. Daily attendance (number of boats at anchor) between April 2018 and late August 2019, in the Bay of L'Elbu. Red crosses (bottom) indicate days when the wind speed exceeded 18.5 km/h. From Schohn *et al.* (2019a).

It is important to note that over-frequentation cannot be defined by threshold values (values often requested by managers). **(i)** These values depend on the local environmental context. **(ii)** These values depend on the expectations of the visitors; e.g., the beach at Nice (Baie des Anges, French Riviera) is not overcrowded, because the bathers there love and seek promiscuity; in contrast, the bay of L'Elbu is overcrowded because the boaters seek wild nature there. As stressed by Lindberg *et al.* (1997), the question is not '*How many is too many*' but '*What are the desired conditions?*' **(iii)** These values depend on the 'character' of the area considered. **(iv)** In fact, things must be seen the other way around: Is there an impact on the environment and on visitors' perception of wilderness? If so, there is overcrowding. This is well illustrated by the case of the osprey (see § 3.3.5): there is over-frequentation **because** a concordant body of scientific studies shows that the decline in reproductive efficiency is due to boats approaching the nests.

Figure 47. Boaters visiting the Scàndula Nature Reserve (SNR), causing the flight of the neighbouring osprey (top left) from its nest (hidden in the cliff) (photo © Olivier Duriez, 2019).

4.2. Global warming

In summer 2003 (early June to mid-August), Europe suffered an **exceptional heat wave**, with a dramatic impact on human health and the terrestrial environment, unprecedented since at least 1500 CE (Luterbacher *et al.,* 2004). This heat-wave also affected marine ecosystems in the northwestern Mediterranean, with extensive mass mortality of invertebrates (mainly gorgonians and sponges) (Garrabou *et al.,* 2009). Catalonia and Balearic Islands were the least affected regions, the gulfs of Genoa and Naples displayed the highest impact, while Provence and Corsica (Scàndula) showed a moderate impact.

In the SNR, populations of the gorgonian *Paramuricea clavata* and the red coral *Corallium rubrum* affected by the 2003 heat wave followed different trajectories over the next two decades; some of them showed a general progressive reduction in biomass; many other populations followed collapse trajectories that have brought them to the brink of ecological extinction, probably due to the recurrence of heat wave events (Gómez-Gras *et al.,* 2020). Unfortunately, the 2018 heat wave destroyed the population of *C. rubrum* in the Palazzu cave (Joaquim Garrabou and Olivier Bianchimani, pers. comm.). As the Mediterranean continues to warm, we can expect more mass invertebrate mortalities in shallow waters.

In the same way, the ***Lithophyllum byssoides*** **rims** at Scàndula, including the iconic *trottoir* of Cala Litizia (Fig. 27), are doomed to be submerged by the rise in sea level and become one more fossil rim (Fig. 28).

4.3. Introduced and invasive species

Introduced and invasive species are widespread at Scàndula. Invasive species are introduced species with harmful consequences for ecosystems, the economy and/or human health (e.g. Boudouresque and Verlaque, 2002, 2012; Ojaveer *et al.,* 2014). In the terrestrial part of the reserve, all mammal species, from mice to wild boar, are introduced. In the marine realm, species of macroalgae are the most conspicuous invasive species, especially the red alga *Womersleyella setacea*, of Pacific Ocean origin, which carpets the coralligenous outcrops (Rodríguez-Prieto *et al.,* 1993). It is in the SNR that Cebrian *et al*. (2012) evidenced the strong and consistently negative effect of *W. setacea* on the health status of the gorgonian *Paramuricea clavata*: lower survivorship, higher necrosis rates, and lower biomass. A live colony of the central Indo-Pacific scleractinian *Oulastrea crispata* has been observed at 3 m depth on rocky substrate at Punta Palazzu; this was its first record in the Mediterranean Sea and shipping can be considerered a plausible vector for its introduction (Hoeksema and Ocaña Vicente, 2014).

The recent extirpation of the giant mollusc *Pinna nobilis* from *P. oceanica* meadows was probably caused by an introduced parasite (Boudouresque *et al.,* 2020b). Decades of protection and management were wiped out in one year by a parasite from elsewhere. But the worst is yet to come, with the species of the Red Sea, driven westwards by global warming, which will soon arrive, such as the voracious teleost herbivores *Siganus* spp. (Boudouresque *et al.,* 2017b).

4.4. Diseases

In 1981-1983, a mass mortality of unknown origin decimated populations of the mollusc *Spondylus gaederopus* throughout the western Mediterranean; dead individuals were observed in the Scàndula Nature Reserve in July 1983 (Meinesz and Mercier, 1983). This may have been a natural process, part of predator-prey or parasite-host cycles, but the lack of historical data does not allow us to say this with certainty.

5. Lessons from management

5.1. Historical features

The Scàndula Nature Reserve, established in 1975, has been managed since its creation by the Regional Natural Park of Corsica (RNPC - *Parc naturel régional de Corse - Parcu di Corsica*). Since December 31, 2005, it is dependent on the Corsican regional government (*Cullettività di Corsica – Collectivité territoriale de Corse*) and is managed by the Office for the Environment of Corsica (UAC - *Uffiziu di l'Ambiente di a Corsica - Office de l'Environnement de Corse*) (Franceschi, 2007; Allegrini-Simonetti *et al.,* 2008).

The decree establishing the reserve specifies that, at sea, recreational fishing, spearfishing, collecting animals and plants, scuba diving and the discharge of residues or rubbish are prohibited. Artisanal fishing is theoretically prohibited, like recreational fishing, but the decree provides for exemptions, granted for one year, in the partial reserve (Feracci and Lepaulmier, 1992; Dominici, 2007). Mooring is prohibited in the integral reserve, and restricted to 24 h in the partial reserve (*Arrêté préfectoral* of May 19, 2000). On land, hunting, camping, lighting fires, uprooting plants or trees, destroying nests and eggs, as well as taking photos and film too close to animals, are prohibited (Feracci and Lepaulmier, 1992; Dominici, 2007; Franceschi, 2007).

In the 1970s, speculators planned to build luxury housing estates to the immediate south-east of Scàndula. The opposition of local populations and Corsican public opinion thwarted what the Corsican press qualified as a 'Scandal in Scàndula', to use one of its hard-hitting titles. These lands were permanently protected thanks to their purchase in 1992 by the *Conservatoire du Littoral*, a French state agency (Richez and Richez Battesti, 2007).

Since December 15, 1983, a vast area extending from the Gulf of Portu (in the south) to Galeria (in the north) has been registered on the **World Heritage List** (UNESCO); it includes the Calanche of Piana, the Gulf of Ghjirulatu and the Scàndula Nature Reserve (Feracci and Lepaulmier, 1992; Dominici, 2007; Luciani, 2016). In 1985, the SNR achieved the category A diploma awarded by the **Council of Europe** for its exemplary management; this diploma was renewed in 1990, 1995, 2000 and 2010 (Feracci and Lepaulmier, 1992; Parc Naturel Régional de Corse, 2004; Conseil de l'Europe, 2015). As early as 1983, the Committee of Experts of the Council of Europe drew the attention of RNPC to sightseeing boats: '*The growth of this kind of tourism should be monitored and kept within narrow limits before an irreversible 'me-too' process is set in motion* (…)' (Biber, 2019). In 2010, the renewal of the diploma by the Council of Europe was accompanied by two conditions and seven recommendations, summarized as follows (Biber, 2019). **(i)** The reserve, too small to play its role effectively, should imperatively be enlarged. **(ii)** Steps should be taken to reduce the impact of anchoring on the *Posidonia oceanica* meadows. **(iii)** Tourism-related activities, '*especially nautical activities, which cause major disturbance to species, in particular certain fish species and osprey*', should be better controlled (Biber, 2019); measures should be put in place to regulate and limit their flow (Zyman, 2020). '*Any boat trip operators which fail to do so* (…) *should not be allowed into the integral section of the reserve*' (Biber, 2019). **(iv)** '*Increase the operating budget and the scientific research budget. Continue to draw on the work of the scientific committee*'. **(v)** '*Allow fishing only with highly selective gear and introduce medium or long-term bans on trammel nets in areas populated with stands of deep* Cystoseira (…)'.

Unfortunately, these demands were not met, as noted by the expert of the Council of Europe during an on the spot appraisal in July 2018. Among the factors that shocked the expert the most, we can cite the number of boats present in the reserve, the excessive speed of most of them (more than 90%) (much higher than the authorized 9 km/h) and the behaviour of the boat trip operators, who arrived at full speed just under the osprey nests, from which the adults flew away and uttered their distress calls (Biber, 2019). The Council of Europe very logically sanctioned in 2021 the SNR by **withdrawing its diploma** (Council of Europe, 2021).

The area between Calvi (to the north) and Carghjese (to the south), including the SNR, belongs to a European Union (EU) Natura 2000 site (Cannac-Padovani and Santelli, 2016). According to Meinesz and Blanfuné (2015), Natura 2000 sites are ficticious protected areas because, among other issues, they do not have any regulations that make them different from unprotected areas (see below).

In the years 1998-2000, a National Park project, based on the coast of the Regional Natural Park (from Calvi in the north to Carghjese in the south), was thwarted by the local population and local elected officials, despite the pledges of increased state funding (Richez and Richez Battesti, 2007).

Since 2008, RNPC and SNR are members of MedPAN, the Network of Mediterranean Marine Protected Areas (MPA) managers. MedPAN, a non-profit organization, has 78 members who manage 110 MPAs and 53 partners from 21 Mediterranean countries. The MedPAN mission is to promote, through a partnership approach, the sustainability and operation of a network of MPAs which are ecologically representative, connected and effectively managed to help reduce the current rate of marine biodiversity loss (Monbrison *et al.,* 2013; Gallon *et al.,* 2019; MedPAN, 2021).

5.2. Changes in paradigms

Throughout history, man has needed scapegoats to justify his errors, his ignorance, his fears or quite simply his stupidity. **(i)** In the 1960s, the cause of all problems (excessive rain, storms, floods, droughts, etc.) was radioactivity linked to Russian ('Soviet') and American nuclear tests. It is true that it was a period of unreason, with radioactivity which reached, in the northern hemisphere, frightening and today unimaginable levels, much higher than the values reached later after notorious accidents at nuclear power plants, at Chernobyl (Ukraine) in 1986 and Fukushima (Japan) in 2011 (Calmet *et al.,* 1988, 1991; Sanchez-Cabeza *et al.,* 2002). **(ii)** In the 1980s the cause of all problems was pollution. It is true that it reached high levels, although sometimes lower than the levels reached tens, hundreds or thousands of years ago (e.g. Zaouali, 1994; Véron *et al.,* 2006). The decrease in fish stocks was not attributed to overfishing and bad fishery practices, but to pollution; some fishers continue to blame pollution for the rarity of some fish species; pollution is obviously a true issue, especially for human health, but, as far as fishery is concerned, no more than a scapegoat (Boudouresque, 2014a). **(iii)** In the 2000s and 2010s, the scapegoat has become global warming (Harari, 2015). There is no doubt that warming is a serious problem, with long-lasting consequences, and that everything must be done to reduce greenhouse gas emissions that cause global warming (e.g. Le Roy Ladurie, 2004; Sicre *et al.,* 2016; Neukom *et al.,* 2019; Sobrino *et al.,* 2020). However, pollution and warming are in no way responsible for the drop in catches; overfishing and, in the eastern Mediterranean, invasive species, have an overwhelming responsibility (Boudouresque and Verlaque, 2010; Bianchi *et al.,* 2014; Maxwell *et al.,* 2016; Boudouresque *et al.,* 2017b). **(iv)** Regardless of the time (decade or century) and place, fishermen have always accused marine mammals of being responsible for the decline of the resource (Gourret, 1894; Faget, 2009; Gerber *et al.,* 2019), rather than their bad practices (see above). In Corsica, it was sometimes dolphins, sometimes monk seals, sometimes both. When foreigners (*furasteri* in Corsican) arrived, as was the case with the Catalan fishers, in 17th century at Marseille (Faget, 2009, 2011), anger was directed towards them (Faget, 2009). Unfortunately for dolphins and monk seals, Catalan fishermen never came to Scàndula. In the same way, raptors were considered pests (Boudouresque *et al.* 2020a); the authors of this article believe that not only hunters, but also fishermen, contributed to the unwarranted extermination of the osprey in the post-World War II years. As Daniel Pauly said convincingly, *'We must not rewrite history […]; it was not the Atlantic seals that wiped out the cod stocks, but the fishermen*' (*in* Grémillet, 2019).

The ecology of the mid-20th century was based on concepts that are now considered a bit naïve. **(i)** Ecosystems were considered to be in equilibrium, in a kind of a biblical vision of lost paradise, while their functioning is today considered to be partly and naturally chaotic (Boero and Bonsdorf, 2007; Boero, 2009; Pavé, 2019). **(ii)** After a disturbance, ecosystems returned to a stage of equilibrium, the climax, *via* an ecological succession (Greene and Schoener, 1972; Ricklefs and Miller, 2005), a climax which is now considered with great caution (Connell, 1978; Sousa, 1984; Frontier, 1999). **(iii)** Disturbances were thought to decrease species richness, while in most cases they increase it: see the Intermediate Disturbance Hypothesis (IDH) (Connell, 1978; Townsend *et al.,* 1997; Imbert *et al.,* 1998; Molino and Sabatier, 2001; Sala and Knowlton, 2006). **(iv)** Following Elton (1958), it was believed that the success of biological invasions was due to disturbance and low specific diversity, while everything shows that there are other factors that explain the success of introduced species (e.g. Bruno *et al.,* 2003; Dunstan and Johnson, 2004; Boudouresque and Verlaque, 2012). **(v)** Biodiversity was reduced to species diversity, while the number of species is only one, perhaps the worst, descriptor of biodiversity (Sala and Knowlton, 2006; Boudouresque, 2014b; Boudouresque *et al.,* 2017b). **(vi)** The species-by-species approach was the rule; the ups and downs in abundance of a species were considered in isolation, rather than in the context of an ecosystem, with predator-prey and parasite-host cyclical fluctuations (see e.g. Bartoli and Boudouresque, 2007; Boudouresque *et al.,* 2020a). Today, the ecosystem-based approach, and even the socio-ecosystem approach, are preferred (Boudouresque *et al.,* 2020a). **(vii)** Nature protection was based on the exclusion of man. Yellowstone Park, in the USA, is a caricatured illustration of this approach, with not only the disastrous eradication of predators (wolves), in accordance with the biblical vision of ecology at the time (predators and parasites were evil), but also the elimination of the native Americans ('first nations') (Cronon, 1996). In order to mitigate the ecological disaster resulting from their extirpation, wolves were reintroduced in 1995 (Fritts *et al.,* 2001).

During its almost 50 years of history, the management of the Scàndula Nature Reserve has been confronted with changes in concepts in ecology. Certain hypotheses, developed in the 1990s, seem totally outdated today. **(i)** Pollution has been blamed for being partly responsible for the giant limpet's decline (Laborel-Deguen and Laborel, 1991), when, as with many of the supposed effects of pollution, the issue is with human health, rather than with the health of populations and ecosystems. **(ii)** The declining trend of the giant limpet (1983 through 1992) within the SNR has been attributed to a depletion of larval supply from depopulated areas (Boudouresque *et al.,* 2005). Possible natural long-term fluctuations, together with the role of predators of the giant limpet, were not taken into consideration; yet, a plethora of species are predators of *Patella ferruginea*, e.g. the mollusc *Stramonita haemastoma* (San Martin *et al.,* 1996; Meinesz *et al.,* 2010; Meinesz and Authoserre, 2012; Meinesz and Dominici, 2015) and the crabs *Carcinus mediterraneus, Eryphia verrucosa, Lunatia poliana* and *Pachygrapsus marmoratus* (Espinosa *et al.,* 2007; Coppa *et al.,* 2012; Meinesz and Authoserre, 2012), the fluctuations in abundance of which are unknown. **(iii)** Docking and disembarking on the *trottoir* of *Lithophyllum byssoides* of Cala Litizia was prohibited in 1995, in order to avoid its degradation by trampling and mooring ropes, following the observations of Laborel *et al.* (1993a) and Verlaque (2010). The entry of boats into the cove was also prohibited. These were relevant measures. But we now know that the speed of sea level rise is a more inexorable cause of degradation than trampling, and that no ban can stop it (Thibaut *et al.,* 2013; Blanfuné *et al.,* 2016b). **(iv)** In a brochure published by the RNPC (Richez and Richez-Battesti, 1992), the tour of the reserve by sightseeing boats was presented in a very positive way, and the brochure ended with advertisements for these companies, which had obviously sponsored it. Today, when over-frequentation constitutes the main threat to the reserve, such a presentation appears to be naïve and inappropriate.

5.3. The Scientific Council

The Scientific Council (SC) of the Scàndula Nature Reserve was set up shortly after the creation of the reserve, in 1979. It has between one and two dozen members, representing the social and biological sciences, both marine and terrestrial domains (history, linguistics, archeology, ichthyology, ornithology, botany, zoology, ecology, etc.). Its members have always been independent of any political authority; they come from the universities of Corsica, mainland France and Spanish

Catalonia. The first chair (1979 to 1992) of this SC was Roger Molinier, who had played an active role in the creation of the Regional Natural Park of Corsica (RNPC - *Parcu di Corsica*) and the SNR. Charles-François Boudouresque succeeded him (1992-2007). Gérard Richez was the last chairman of this council (2007-2015).

In 2015, the government of Corsica (*Cullettività di Corsica*) decided to abolish the SC of Scàndula and to replace it with a 'super-council' common to the entire RNPC. This super-council, oversized and ineffective, hardly ever met before sinking into oblivion. Why was the Scàndula SC abolished? The authors of this article believe that, for the supporters of unlimited tourism, the SC had become an obstacle. In 2019, the new government of Corsica decided to recreate the SC of the SNR. But the RNPC *de facto* excluded independent scientists from field research in 2020, and instead gave local officials the task of carrying out that research. It is important not to confuse the essential monitoring with the no less essential scientific research, which must of course be independent of the administrative authorities. The new paradigm adopted was that there is no evidence that frequentation by sightseeing boats and the noise they generate is the cause of the decline in emblematic fish abundance nor the failure of the osprey to produce fledging chicks, which is in contradiction to what has been demonstrated by rigorous scientific research (Monti *et al.,* 2018a). But this strategy can prove to be counterproductive: will scientists and international organizations trust the new data? Whatever the case, in early 2021, the SNR lost its European Diploma.

In the Mediterranean, as everywhere in the world, most marine protected areas are 'paper parks' or 'mist parks'. **Paper parks** are fictitious protected areas: lines on an official map without park wardens, management plans, scientific council or even a park director. **Mist parks** are protected areas intended to fulfill the international commitments of countries; they are often immense, have a real existence (director, premises, officials), but do not implement any real management measures involving, where necessary, constraints for some of the users. Paper parks and mist parks occur throughout the world, including in European countries, such as France and Spain, and with Italy and Greece leading the pack (Francour *et al.,* 2010; Sale *et al.,* 2010, Sala *et al.,* 2012; Meinesz and Blanfuné, 2015; Boudouresque, 2020; Claudet *et al.,* 2020).

The scientific and management strategy of a protected area should be based upon ten cornerstones (Meinesz and Blanfuné, 2015; Boudouresque *et al.,* 2013; Boudouresque, 2020; Claudet *et al.,* 2020). **(i) Protection and management should be real**, with park wardens enforcing bans (e.g. fishing, anchoring) and zoning according to the various uses (e.g. pastoralism, farming, artisanal fishing, diving, mooring, hiking, bathing). In addition, the wardens of the SNR enjoy police power, that is to say that they can give tickets that have legal value before the courts. This might seem normal, but it is important to underline these points, as they mark a difference of paramount importance with most Mediterranean protected areas. **(ii)** The establishment of **management plans and a scientific strategy** (Barcelo *et al.,* 2013; Di Franco et al., 2016). A management plan has 5 steps: the inventory (species, ecosystems, habitat mapping, state of health), conservation issues (including the impact of human activities), long-term objectives, short-term methods (programmes, action plans) to achieve long-term objectives and finally the assessment of management results, for example by means of bio-indicators. The management plan is drawn up in close collaboration between the manager and the Scientific Council. It must be approved by national (e.g., in France, the National Council for the Protection of Nature) and regional (e.g., in Corsica, *Uffiziu di l'Ambiente di a Corsica* - UAC - and *Cullettività di Corsica*) authorities. It helps organize the work of reserve officers efficiently. The first management plan of the Scàndula Nature Reserve was approved by the SC in 1994, the second one in 2014 (Parc Naturel Régional de Corse, 1994; Tavernier and Dominici, 2014). **(iii) To keep management interventions at a minimum** (Cunha *et al.,* 2012 ; Boudouresque *et al.,* 2017c; Boudouresque, 2020; Boudouresque *et al.,* 2020a). This is based on the fact that a protected area is neither a botanical garden nor a zoo, that its role is not to favour certain species at the expense of others, even if they are protected species, that nature often does things better than humans and that doing nothing sometimes constitutes a management action (Leakey and Lewin, 1995; Boudouresque *et al.,* 2020a). Obviously, keeping management interventions at a minimum does not mean a dogmatic rejection; the experimental work performed at Scàndula on sea urchins and seaweed forests shows that occasional eradication of herbivorous sea urchins can help restore seaweed forests, their unique species community and ecosystem services such as a nursery for some fish species (e.g. Ballesteros *et al.,* 2002). **(iv) The existence of a Scientific Council** (SC) (Boudouresque *et al.,* 2013, 2020; Martin, 2020). This is one of the criteria (but not the only one) which makes it possible to distinguish true protected areas from 'paper parks'. The SC should be made up of leading scientists chosen on the basis of their field of expertise, but also their real knowledge of the protected area through the research they have been able to develop there. They should not be theoretical experts, disconnected from the reality on the ground. This knowledge of the field allows them to see, to 'feel' emerging issues that could go unnoticed by the staff of the protected area. Obviously, members of the SC should be **independent** of local or national authorities. **(v) A slow renewal of SC members**. Reconstitution of the SC, at regular intervals, should be based on a balance between rejuvenation, the necessity of making room for new disciplines, and continuity. It is important that the SC 'culture', its capacity for 'co-evolution' in phase with the Scientific Department and the Director of the protected area, should not be lost. **(vi) The authority of the SC**. A Scientific Council should not be just a showcase. Experts disconnected from reality can discuss matters freely and expertly, and give opinions that may be either unrealistic or relevant, but which in both cases will go no further than the door of the meeting room. By definition, a SC has no decision-making power, just an advisory role. But, especially if it works closely with wardens, the curator and the director, major disagreements should be the exception. By validating the advice of the SC, the management affords it respect and credibility, and in turn this promotes the social acceptability of management decisions that the protected area may have to make. In addition, since governance requires consultation with users and stakeholders, the SC can participate in this consultation and in the necessary explanations. **(vii) Active scientific research**. Scientific research constitutes a pivotal basis for protection and management: we only effectively protect and manage what we know well. From its creation, le SNR has been the site of very active research (Antona *et al.,* 1981); today, it is one of the best known sites in the Mediterranean. Over time, the priorities have of course changed, the inventories of species and habitats giving way to more work focused on e.g. ecosystems, management and social sciences. **(viii) Close collaboration between the agents of the protected area and scientists from outside**. The involvement of the agents of the protected area in research is essential. In Scàndula, from the creation of the reserve to 2005-2010, we can speak of a real symbiosis between the director of the RNPC, the SNR agents (the wardens and the curator) and the scientists. The collaboration with independent scientists, including members of the SC, is essential, as it ensures the credibility of the data, in a win-win scenario. Certain protected areas, where external scientific teams do not participate in the data collection, can be suspected of providing their governments and international organizations with data that we might tactfully qualify as politically correct. **(ix) Publishing a scientific journal**. Unpublished works (gray literature), even when they are, often provisionally, available on the internet, quickly fall into oblivion. It is not uncommon for a government agency (sometimes the French Ministry of the Environment itself) to fund studies on a subject on which unpublished studies already exist. Publishing a scientific journal, for an annual cost sometimes lower than the cost of a single study, therefore represents an economical and efficient use of public money **(x)** A final cornerstone is the involvement of fishermen (and other stakeholders) in the management of the protected area (Di Franco *et al.,* 2016; Dahlet and Sánchez Lizaso, 2021), e.g. as members of the Board of Directors.

The Regional Natural Park of Corsica (RNPC) and the SNR meet (or met, until 2010) all these conditions (cornerstones). It is, or was (with the Port-Cros National Park and the Parc Marin de la Côte

Bleue, in eastern and western Provence, respectively) one of the rare cases in the Mediterranean to fulfill all these conditions (Boudouresque *et al.,* 2013; Astruch *et al.,* 2018a; Bachet, 2020). The RNPC and SNR owe this to a charismatic director, Michel Leenhardt, and to François Giacobbi, then president of the government of Corsica (*Conseil régional de Corse*). Michel Leenhardt graduated from the French *École du Génie Rural et des Eaux et Forêts*, then from the prestigious *École Polytechnique*; he headed the Mission for the creation of the RNPC in 1969. In 1971, he was the first director of the RNPC, and he remained so until 1997 (Fig. 48). Michel Leenhardt kept repeating and hammering home: '*Never stray far from the scientists!*' This principle should be reiterated loud and clear in all environmental agencies; the interests of tour operators and the boat trip business must be taken into account, but tour operators are not scientists. As a Corsican proverb says, *Ognunu s'occupa di e so pecure è e sterpe sarranu assestate bè cum ellu ci vole* (If everyone does his part, even the cows will be well-kept).

The last issue of the scientific journal of the RNPC was the number 62, dated 2005. Ironically, it was introduced by a preface by the then Chair of the RNPC Scientific Council, highlighting the importance of the journal and praising its revival (Gauthier, 2005). 2005 perhaps marks the date of the beginning of the decline of the RNPC and the SNR, which were, until then, among the most emblematic examples of effective environmental protection and management.

Figure 48. Left to right, at Galeria: Michel Leenhardt, X, Charles-François Boudouresque and Nardo Vicente in 1999. Photo © Alexandre Meinesz (courtesy of the author).

5.4. Management strategy

For most environmentalists, managers and stakeholders, the paradigm of a Marine Protected Area (MPA) is the banning of all human activities, mainly artisanal fishery (No-Take Zones, NTZs), but sometimes also diving, anchoring and even sailing and bathing. Most Mediterranean MPAs are based on a NTZ, usually accompanied by a buffer area (where only recreational fishing is prohibited) and a transitional area (no prohibitions, just an obligation to abide by the general regulations – which are not enforced elsewhere). Other MPAs, such as the Port-Cros Archipelago (Port-Cros National Park) can clearly be assigned to the MUM type (Multi-Use Management), characterized by complex zoning of the MPA, based on the uses, conservation goals for the habitats and ecosystems and clearly displayed priorities (e.g. artisanal fishing rather than recreational fishing). It is worth noting that, as far as the conservation of the natural heritage and the functioning of ecosystems are concerned, MUM management can be as efficient as NTZ management (Ulate *et al.,* 2018; Boudouresque *et al.,* 2019; Raimbault *et al.,* 2021); in addition, it is compatible with sustainable fisheries in particular, sustainable development in general, and fits well with the concept of the socio-ecosystem: conservation goals are in phase with how people understand, use, and interact with their surroundings (West and Brockingston 2006; Boudouresque *et al.,* 2020a). The Scàndula MPA management can be considered as intermediate between NTZ and MUM strategies: it has a central NTZ where bathing, diving and anchoring are prohibited, although boat traffic is permitted, and a partially protected buffer area that allows artisanal fishery, with some constraints (see § 3.6.3). The problem with MUM management is that in much of the world it is an alibi for the lack of real management and/or binding measures, so that there are no differences in the ecosystem functioning between within-MPA and outside-MPA.

In any case, what matters is **(i)** that an MPA has effective regulation and **(ii)** that regulation is strictly implemented. This is quite rare in the Mediterranean, but this has been the case with the Scàndula Nature Reserve since its creation in 1975. Thanks to exceptionally motivated wardens and curators (e.g. Jérémie Achilli, François Arrighi, Charles-Henri Bianconi, Jean-Laurent Dominici, Jean-Marie Dominici, Gérard Feracci, Franck Finelli, Virgil Lenormand, Pierre Mariani, Roger Miniconi, François Paolini, Nicolas Robert, Julien Tavernier), the surveillance of the reserve was effective, leading to dozens of tickets accompanied by the seizure of the equipment used (harpoons, diving suits, scuba tanks, boats, etc.). The emblematic paroxism of this surveillance is the boarding of the cruise ship Europa 2, in 2016, illegally anchored in the SNR and preparing to dump dozens of inflatable boats and thousands of tourists there (Fig. 49). Facing the curator of the SNR, towering over his tiny inflatable boat, the giant cruise ship weighed anchor and left. All things considered, it is difficult not to think of the famous 'tank man' (unknown protester) who stood in front of a column of tanks, on June 5, 1989, in the Tienanmen Square, Beijing (China).

Figure 49. On board his tiny inflatable boat, Jean-Marie Dominici, curator of the Scàndula Nature Reserve, challenges the giant cruise ship Europa 2, illegally anchored in the SNR, and which is about to dump thousands of visitors there. In the background, some of the inflatable boats which were to take part in the sightseeing trip. The cruise ship weighed anchor, and this event constitutes one of the emblematic episodes of the management of the SNR. From a France 3 Thalassa TV show (François Guillaume).

5.5. Economic value

The World heritage (UNESCO) site of Corsica, from Galeria to the Gulf of Portu, including the Scàndula Nature Reserve (SNR), with 11 800 ha, contributes to 28-44 % of the tourism attractiveness of Corsica and 22 % of tourism revenue (Luciani, 2012, 2013). Overall, 44 % of tourist spending throughout their stay in Corsica (13 days on average) is attributable to the UNESCO site of Corsica (Table IX; Luciani, 2012). 68 % of site visitors have indicated their intention to return. 94 % of visitors say they will recommend their family and friends to visit the site. Tourism in Corsica represents 13 % of the GDP (Gross Domestic Product). The site was visited by 1 100 000 people in 2012, from April to October (Luciani, 2013, 2016). It generates 312 M€ per year in economic benefits (261-387 M€ in turnover and 30-46 M€ in tax benefits). 2 673-3 626 direct and indirect jobs are linked to this site. Its notoriety generates 1.3 M€ of image impact (Luciani, 2012, 2013, 2016).

5.6. Some lessons: successes and failures

(1) The reversal of the decline of the osprey in Scàndula and Corsica, and the slow restoration of its numbers (at least until 2010; see above) are a major success. The reintroduction of the osprey in

Tuscany, from Corsican individuals, constitutes an even more important success: the examples of successful reintroduction of species are very rare (Thibaut and Patrimonio, 1990; Dominici, 2020; Monti *et al.,* 2014). But the decline in reproductive success of the osprey in the SNR due to excessive tourism pressure (Monti et al., 2018a) and the inability of the authorities to respond to a threat that goes against the goals of the reserve is a management failure. As early as in 1999, the Committee of Experts of the Council of Europe warned RNPC about the disturbance of ospreys by sightseeing boats and recommended preventing boats approaching the nests too closely (Biber, 2019). This was a major reason that prompted the Council of Europe to withdraw Scàndula's European Protected Area label (European Diploma) in 2021.

Table IX. Estimate of the allocation rate for expenditure related to the UNESCO site of Scàndula, Corsica. The method is that defined by *Grands Sites de France*. After Luciani (2012).

Questions to 550 tourists	Percen-tage	Rate of assignment of the site effect according to the reasons for the visit	Allocation rate
You have come to Corsica to visit this site **specially**	10.2 %	100 %	10.2 %
This site was an **important** objective of your visit during your stay	33.3 %	66 %	22.0 %
This site was a **possible** objective of visit during your stay	34.8 %	33 %	11.5 %
You **did not know** the existence of this site before coming to Corsica	21.9 %	0 %	0 %
Total respondents		Weighted average rate	43.6 %

(2) The attraction represented by the reserve, its beauty as well as its biological richness, is at the heart of conflicts of use between heritage protection and frequentation. These conflicts are classic in protected areas, coveted by tourism operators: protection of natural heritage vs. openness to visitors, sustainable management of nature vs. management of business activities that are dependent on welcoming tourists and their demand for the spectacle of nature, legitimate and reasoned use of a public good by local companies vs. what they risk losing by their uncontrolled exploitation (Richez and Richez Battesti, 2007).

Overall, tourists are aware of the existence of a Natural reserve and agree with the bans (Richez, 1988; Schohn *et al.,* 2019a). However, that does not mean much, as long as sightseeing boats do not follow the rules. It is well known that the European public is in favor of the strong protection of distant species (elephants, lions, tigers, etc.), but is more divided when it comes to tolerating the impact of the wolf, near their home: there is the famous aphorism: 'yes, but not in my backyard' (NIMBY) (Gobert, 2015). Although usually insignificant, this impact can be exaggerated by witnesses and instrumentalized by the media (see the slaughter of monk seals and ospreys, § 3.4 and 3.5).

Boat trip owner involvement in managing the frequentation of the SNR is important; however, as stressed by Jentoft and McCay (1995), user participation is a means through which users are empowered, and there is always a possibility that some (users) will win while others (natural heritage) will lose. In Scàndula, despite warnings from the Scientific Council (SC) since the beginning of the 2000s, then those from the Council of Europe since 2010, the manager (RNPC and UAC - *Uffiziu di l'Ambiente di a Corsica*) was unable to anticipate the surge in frequentation; in 2015, it just 'killed the messenger', i.e. abolished the SC.

(3) The competition between fishermen and monk seals. Social science studies compiled testimonies from former fishermen justifying the extermination of monk seals by the terrible damage they supposedly inflicted on their nets. But none of those studies critically analyzed the reliability of human testimony. None noticed that the osprey has been exterminated in exactly the same way, despite the fact that it does not compete with fishermen. None considered that these testimonies, presented with the empathy that everything that comes from the past seems to merit, could be simply representative of human ignorance.

(4) The pressure of anchoring. Anchoring has a well-known negative impact on *Posidonia oceanica* meadows (e.g. Porcher, 1984; Milazzo *et al.,* 2004; Ceccherelli *et al.,* 2007; Lloret *et al.,* 2008; Boudouresque *et al.,* 2009, 2012). The vulnerability of the meadows of Scàndula was highlighted by Schohn *et al.* (2019a). At Scàndula, anchoring is only banned in the tiny integral reserve; it is authorized everywhere else, not only in the partially protected reserve (buffer zone), but also in the whole area from Carghjese to Calvi, in particular in the gulfs of Ghjirulatu and Galeria. However, solutions do exist, e.g. the eco-designed mooring 'Harmony', developed and successfully tested in the Port-Cros National Park (Provence, France), which does not harm the *P. oceanica* meadow owing to its anchoring system (using helical screws), and intermediate buoys, which prevent the chains from eroding the meadow (Francour and Robert, 2000). Roger Miniconi's proposal (1997) to install such moorings at Ghjirulatu, Galeria and L'Elbu, was not acted on. More than 20 years later, the very minimalist, sometimes ecologically naïve, Natura 2000 charter for the Carghjese-Calvi sector does not even recommend the deployment of such moorings (Office de l'Environnement de la Corse, 2020).

(5) The pressure of artisanal fishing is theoretically controlled by the signing of a charter by the fishermen authorized to fish, and by the number of authorizations issued each year (see § 3.6.3). But unlike Port-Cros National Park, where the constraints linked to the fishing charter are reassessed each year (Boudouresque *et al.,* 2004, 2005; Cadiou *et al.,* 2009; Robert *et al*., 2013; Astruch *et al.,* 2018a; Rouanet *et al.,* 2020b), this is not the case at Scàndula. As a result, the fishing pressure has become too strong (Verlaque *et al.,* 1999b; Personnic *et al.,* 2014; Boudouresque *et al.,* 2015), without the RNPC staff daring to negotiate with the fishermen to update this charter. The decline of seaweed forests and the extension of barren grounds overgrazed by sea urchins testify to this excessive fishing pressure.

In addition, a regular *in situ* survey, with a two- to three-year interval, of the fish population (density, biomass, species richness, abundance of heritage value species and of target species of the artisanal fishery), and key invertebrate species, is lacking, despite repeated requests from the SC. Such a survey would have enabled the SNR to better play its role of reference in the Mediterranean, and RNPC officials to better manage artisanal fishing and emblematic species, in the framework of a socio-ecosystem-based approach.

(6) Invasive species. Man, who arrived in Corsica around 10 000 BP, more or less quickly exterminated all native non-flying terrestrial mammals; it was the Sardinian pika *Prolagus sardus*, an herbivore roughly resembling a rabbit, which resisted the longest. All the mammals present today have been introduced. This is a considerable upheaval, of course irreversible, of terrestrial ecosystems and their functioning (Vigne and De Lanfranchi, 2012; Médail *et al.*, 2017). In the marine realm, the arrival of invasive species is more recent. Their impact is growing (see § 4.3). Unfortunately, their eradication is impossible; the solution lies in prevention, that is to say the control of vectors: ship hulls, ballast water, the aquarium trade, etc., this type of control should take place at the scale of Corsica or the EU rather than that of the SNR.

(7) The overall 'non-interventionism' approach in the management of the terrestrial ecosystems at Scàndula ultimately allows much more effective and less expansive ecosystem conservation than naïve *ad hoc* operations for the management of these environments. As an exemple, **the presence of a small herd of feral goats** (goats abandoned by their former owners) did not immediately worry the officials of the reserve. When they began to proliferate, the Scientific Council worried about the impact of grazing on the maquis ecosystem (Bioret, 2002); possible control methods were reviewed. But since then, their abundance has naturally declined: the golden eagle has incorporated juvenile goats into its diet (Virgil Lenormand, pers. comm.). Sometimes natural processes do things better than humans; doing nothing is also a management measure.

(8) The incredible *'millefeuilles'* of the management of Scàndula and its region. The *millefeuilles* ('thousand sheets') is a French pastry made up of several alternating layers of puff pastry and pastry cream. Superimposing a French national reserve (SNR), a Corsican reserve (planned), a UNESCO site, a MAB site and a Natura 2000 site, the UAC (*Uffiziu di l'Ambiente di a Corsica*) makes the legislation illegible, and therefore hardly capable of preventing the devastating effects of excessive tourism.

(9) A deficit in the social sciences and in the ecosystem-based approach. **(i)** Although the Scàndula's Scientific Council has always included representatives from the social sciences, biologists have been more active and more dynamic than the former. Only the study of artisanal fishing, at the border between biology and the social sciences, has given rise to long-term studies. It is a pity that the uses, the perception by users and the local population, the possible misunderstandings between the SNR and local inhabitants, have left few traces during the almost 50 years of existence of the SNR. **(ii)** With regard to biology and ecology, the approach was mainly based on outstanding species (e.g. *Posidonia oceanica*, grouper, osprey) or taxa (e.g. ants, terrestrial plants) than on the functioning of ecosystems. An ecosystem-based approch to management (see e.g. Boudouresque *et al.,* 2020a) remains to be developed in the SNR.

(10) The French decree establishing the SNR in 1975 should have been updated. This was, moreover, one of the Council of Europe's requests (as early as 1988) for the possible renewal of the European Diploma (Biber, 2019). Such an update is a lengthy administrative procedure. This is not the place to determine the respective responsibility of the RNPC and the French Ministry of the Environment for never updating the 1975 decree.

6. Conclusions

6.1. Scàndula: A hotspot of scientific knowledge

After nearly 50 years of intense and uninterrupted research, the Scàndula nature reserve is today one of the best-known sites in the whole Mediterranean. It owes this in particular to a 'visionary' director, Michel Leenhardt, deeply aware of the essential role of research in a protected natural space, and to a President of the Scientific Council, Roger Molinier, whose vision of science was global and humanistic, in a way ahead of his time; deceased in 1991, Roger Molinier did not live to see the Rio summit and the emergence of the concept of sustainable development, of which he was a precursor (Molinier, 1991; Boudouresque, 1992; Boudouresque and Olivier, 2013).

Being a hotspot for scientific knowledge is not just a matter of numbers for the Guinness Book of Records. In most regions of the world, scientific knowledge is in the form of snapshots: one to three years of follow-up (the duration of a doctoral thesis), at a given point, to which the researcher never returns. A hotspot like Scàndula makes it possible to have, at the same site, data on all ecosystems, all ecosystem compartments, and to follow them over time (i.e. the concept of LTER - Long-Term Ecological Research). The SNR has thus become a unique place where an ecosystem-based approach can be tackled, and therefore allow understanding of what is happening, not only at the scale of the nature reserve, but at global scale (Boudouresque *et al.,* 2020a).

Unfortunately, since 2015 and the abolition of the Scàndula Scientific Council, a certain number of scientific monitoring programmes have gradually ceased, the field missions have become more distant and the collaboration of Reserve officials with independent scientific teams has been made difficult for administrative reasons (or pretexts?). In 2019 and 2020, some Corsican officials allowed excessive and highly damaging tourist practices, which are against the Decree that founded the SNR (including the ban of commercial activities in the reserve and the use of loudspeakers; Decree no. 75-1128 of the French Republic, December 9, 1975).

6.2. Scàndula: a hotbed of scientific discoveries

Thanks to the concentration of multidisciplinary research at a single site, the number of major discoveries that have originated at Scàndula is impressive. What follows does not claim to be exhaustive.

(1) It was at Scàndula that Ballesteros *et al.* (2009) discovered that the brown alga *Cysoseira zosteroides* was a very long-lived species, thus justifying the use of the term 'forest' for its stands.

(2) It was at Scàndula, or in its immediate vicinity, that two types of seagrass meadows, **(i)** the **hill meadow** and **(ii)** the **tiered meadow**, were discovered, and that the mechanism of their construction was understood.

(3) It was at Scàndula that **(iii) lepidochronology**, the marine equivalent of dendrochronology (the study and interpretation of tree trunk rings), was discovered by Alexandre Meinesz and one of the authors (CFB); lepidochronology has become a sort of Swiss army knife, a multipurpose tool; hundreds of scientific publications now use this tool.

(4) It was at Scàndula (L'Elbu Cove) that the first **permanent quadrat** and almost the first ***balisage*** (with cement markers) of the lower limit of the *P. oceanica* meadow were put in place; the scientific results have been considerable, on the scale of the whole Mediterranean, with major consequences for the management approach.

(5) Scàndula is almost the only site in the Mediterranean where almost **metric scale maps** of the presence and abundance of several species (e.g. the brown alga *Cystoseira amentacea*, the red alga *Lithophyllum byssoides*, the actinian *Actinia mediterranea*, the mollusc *Patella ferruginea*) are available (Bianconi *et al.,* 1987; Meinesz *et al.,* 1999). In a world where dozens of authors, in hundreds of publications, in prestigious journals, talk about climate change, on the basis of theoretical models and despite a real world that they do not know at all, it is reassuring that real data do exist. And it is in some areas such as Scàndula that such data, a **true baseline**, do exist.

(6) It was at Scàndula that **untouched populations of the red coral** *Corallium rubrum*, a species intensively exploited since Antiquity, were discovered; an underwater cave harbours (or harboured before the occurrence of a heatwave) the largest biomass (by more than 100-fold) of *C. rubrum* reported to date in the Mediterranean (Garrabou *et al.,* 2017).

(7) It was at Scàndula that Bartoli *et al.* (2005) showed that the richness in **fish parasites** is an indicator of the good health of an ecosystem: the less the ecosystem is disturbed, the greater the diversity of the parasites; this often surprises those whose notions of ecology are modest, or date from the middle of the 20th century.

(8) It was at Scàndula that the 'dark side' of the **cascade effect** (within the reserve effect), the extreme rarity of invertebrates, including the sea urchin *Paracentrotus lividus*, was shown for the first time in the Mediterranean Sea (Boudouresque *et al.,* 1992b). This has considerable implications for the management of coastal ecosystems throughout the Mediterranean (see e.g. Boudouresque and Verlaque, 2020; Boudouresque *et al.,* 2020b). It is also at Scàndula that the possible buffer effect (within the reserve effect) was suggested (Francour and Bodilis (2004).

(9) It was at Scàndula that the **nursery** role of the *Posidonia oceanica* meadow, often assumed, was demonstrated for the first time (Francour and Le Direac'h, 1994, 1998).

(10) It was at Scàndula and in Port-Cros national Park the same year, in 2000, that the first **fishing effort surveys** were implemented in French MPAs, with a now well-known interest in the fisher's knowledge and the beginning of co-management approaches.

(11) It was at Scàndula that the first studies on the populations of the **fan mussel** *Pinna nobilis,* an iconic Mediterranean endemic, began (at the same time as in the Port-Cros National Park) (Vicente and Moreteau, 1988). Thanks to protection and management measures, the species there reached the highest population density in the Western Mediterranean (Vicente and Trigos, 2013).

(12) It was at Scàndula that a long-term series of remarkable duration (1984 through 2019) of the dynamics of osprey *Pandion haliaetus* populations was established. This exceptional long-term series constitutes the scientific basis for considering that over-frequentation by boats, in particular sightseeing boats, is the most probable cause for the decline in the reproductive success of the osprey.

(13) It was at Scàndula that the first **Self-Activating Photographic Device** (SAPD) was set up, in a Mediterranean MPA, offering the means to obtain precise data on the frequentation by boats (Schohn *et al*., 2019a).

6.3. Scàndula, a fragile global monument: handle with care!

In almost 50 years, the Scàndula Nature Reserve has become a monument in the Mediterranean, for its marine ecosystems perhaps close to the baseline, for its terrestrial ecosystems rapidly changing towards a state that will certainly not be the baseline but that it will be interesting to know, and for the flawless protection it has enjoyed. It owes this to visionary managers (Regional Natural Park of Corsica), to passionately dedicated wardens and curators of the reserve and to their close collaboration with scientific teams from Corsica, mainland France, Italy and Catalonia.

In contrast to the European trend at the start of the third millennium, when the perception of ecological issues is growing, the authors have the feeling that Corsica has experienced an opposite trend. Corsica was far ahead in the 1970s, when the trio François Giacobbi (President of the Corsica region), Roger Molinier (a scientist) and Michel Leenhardt (the director of the RNPC) were strongly supported by Corsican public opinion. Today, some Corsican politicians and the media support (directly or *de facto*) ideas quite distant from those of the founding fathers of the SNR.

As stressed by Sala *et al.* (2021), a highly protected, well enforced and managed MPA (such as Scàndula Nature Reserve) is worldwide a win-win multi-goal tool which maximizes benefits for biodiversity (and associated services), food provision (fisheries) and climate change mitigation (*via* carbon sequestration).

Will the essential extension of the Scàndula reserve, under development for more than 30 years, ever be realized? And if so, will it be managed by the *Uffiziu di l'Ambiente di a Corsica* (UAC), together with the Scientific Council and elected officials, or by the commercial interests? Whatever the case, the Scandula Nature Reserve is a respected and recognized model in the Mediterranean, and it attracts considerable economic benefits to Corsica. Are some business interests ready to kill the goose that lays the golden egg for immediate but short-lived benefits? A Corsican proverb says: *Un manghjete micca u vitellu in corpu di a vacca* (You must not eat the calf in its mother's womb). In the Mediterranean, 90 % of Marine Protected Areas are paper parks, i.e. fictitious protected areas; in contrast, the SNR has been an exemplary model, and hopefully it will continue to be so in the future. As Napoleon Bonaparte's Corsican mother Letizia Bonaparte used to say: *Pruch'ella duri* (May it last!).

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